United States
Department of
Agriculture

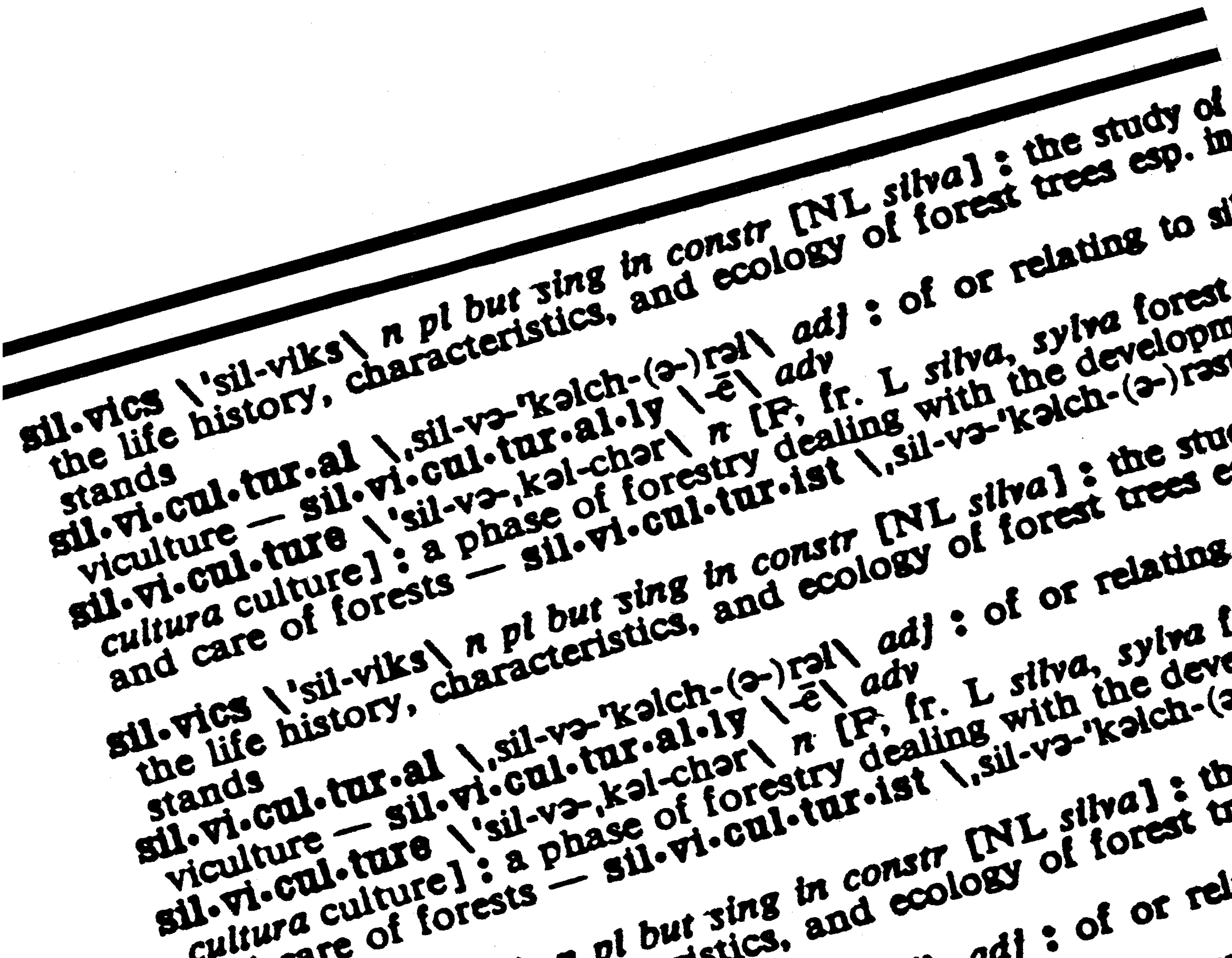
Forest Service

**Southern
Research Station**

General Technical
Report SRS–48

Proceedings of the Eleventh Biennial Southern Silvicultural Research Conference

Knoxville, Tennessee
March 20–22, 2001



DISCLAIMER

PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife if they are not handled or applied properly. Use all herbicides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and their containers.

Papers published in these proceedings were submitted by authors in electronic media. Some editing was done to ensure a consistent format. Authors are responsible for content and accuracy of their individual papers and the quality of illustrative materials.

February 2002

Southern Research Station
P.O. Box 2680
Asheville, NC 28802

Proceedings of the Eleventh Biennial Southern Silvicultural Research Conference

Edited by
Kenneth W. Outcalt

With Assistance from
Patricia A.Outcalt
and
Robert B. Tucker

Knoxville, Tennessee
March 20-22, 2001

Hosted by
USDA Forest Service, Southern Research Station
The University of Tennessee, School of Forestry, Wildlife, and Fisheries

Sponsored by
The University of Tennessee, School of Forestry, Wildlife, and Fisheries
1890 Colleges and Universities
National Association of Consulting Foresters of America
National Association of Professional Forestry Schools and Colleges
National Hardwood Lumber Association
Society of American Foresters
Southern Group of State Foresters
Southern Industrial Forest Research Council
USDA Forest Service, Southern Research Station

Published by
USDA Forest Service
Southern Research Station
Asheville, North Carolina
February 2002

PREFACE

The Eleventh Biennial Southern Silvicultural Research Conference was held March 19-22, 2001, at the downtown Hilton in Knoxville, TN. This conference continued the tradition of serving as a forum for the presentation and exchange of research information on southern silviculture. There were 114 oral presentations and 58 posters presented to the 400 plus attendees. This report contains papers from the oral presentations made during the four concurrent sessions conducted over 2 days and from the poster session. It also contains extended abstracts from a special session on long-term trends in loblolly pine stand productivity and characteristics. Field trips were taken on March 22 to Joyce Kilmer Memorial Forest to visit an old-growth cove hardwood forest and the University of Tennessee, Forestry Experiment Station, Oak Ridge research site to look at studies on tree growth in elevated carbon dioxide environments, establishment of pine–hardwood mixtures and throughfall measurements.

The work of the steering committee that helped plan the meeting, review the abstracts, make the arrangements, etc. is gratefully acknowledged. The success of this meeting is the result of the diligent work of this committee that consisted of:

Wayne Clatterbuck (Local Arrangements Chair)
University of Tennessee, Dept. of Forestry, Wildlife, and Fisheries, Knoxville, TN
Robert Doudrick (Conference Chair)
USDA Forest Service, Southern Research Station, Asheville, NC
Dave Haywood (Past Program Chair)
USDA Forest Service, Southern Research Station, Pineville, LA
Pauline Spaine
USDA Forest Service, Southern Research Station, Athens, GA
James Guldin
USDA Forest Service, Southern Research Station, Monticello, AR
Ric Jeffers (Registration and Proofing)
USDA Forest Service, National Forest System, Atlanta, GA
John Kush (Poster Session Coordinator)
Auburn University, Auburn, AL
Andy Ezell (Student Awards Coordinator)
MS State University, Mississippi State, MS
Michael Messina,
Texas A&M University, College Station, TX
Phil Dougherty (Special Session Co-Chair and Moderator Recruitment) Westvaco, Summerville, SC
John Kushla
Rayonier, Yulee, FL
Eric Jokela (Special Session Co-Chair)
University of Florida, Gainesville, FL
Brian Lockhart (Student Awards Judging Coordinator and Meeting Evaluation)
Louisiana State University, Baton Rouge, LA
Ralph Amateis
Virginia Polytechnic Institute, Blacksburg, VA

Partial funding for the conference was provided by the Southern Research Station and the University of Tennessee. The Southern Research Station gratefully acknowledges the University of Tennessee, Department of Forestry, Wildlife, and Fisheries for handling the fiscal matters and making all the financial arrangements with the conference hotel and handling registration. Special thanks go to Dave Haywood for valuable advice and guidance, to Allyson Muth from the University of Tennessee for many office tasks and for taking charge of registration, to the many University of Tennessee students who ran audio visual equipment, drove vans, and helped unload and load poster boards, and to Vic Ford of Westvaco who graciously agreed to handle the Continuing Education Credits from Society of American Foresters. Helen Mohr, Ross Phillips, and Greg Chapman assisted with the unloading, setup, and loading of the many poster boards. Shirley Greer and Mike Allen helped stuff envelops, assemble nametags, and package registration folders. We gratefully acknowledge Dale Brockway, USDA Forest Service, Southern Research Station, Auburn, AL, for judging student posters and all the others who assisted with the student awards program by evaluating oral presentations.

Special recognition is given to the moderators who led each session and kept everyone on time, which included: Tom Fox, Jack Gnegy, David South, Mary Ann Sword, David Van Lear, Clark Baldwin, Alex Clark, Marshall Jacobson, George Hooper, David Moorhead, Nancy Herbert, Brian Lockhart, Wayne Clatterbuck, Jim Guldin, Ralph Amateis, Ken Outcalt, John Tolbert, Paula Spaine, and Eric Jokela and to the tour leaders–David Van Lear and Wayne Clatterbuck.

A special thanks goes to Patricia Outcalt for many hours of work including editing the mailing list, preparing the brochure and the book of abstracts, and creating and updating the Web page for the conference.

Papers published in this proceedings were submitted by the authors in electronic media. Limited editing was done to ensure a consistent format. Authors are responsible for content and accuracy of their individual papers.

Kenneth W. Outcalt
Program Chair
Southern Research Station, Athens, GA

CONTENTS

Pine Nutrition

Moderators:

TOM FOX
VPI

and

Marshall Jacobson
The Timber Company

BIOMASS, NITROGEN, AND PHOSPHORUS ACCUMULATION IN 4-YEAR-OLD INTENSIVELY MANAGED LOBLOLLY PINE AND SWEETGUM PLANTATIONS

Charles A. Gresham and Thomas M. Williams[1]

Abstract—Knowing the nutrient uptake potential of plantations of fast-growing species is essential to designing land-based tertiary water treatment facilities. This study was conducted to estimate the biomass of 4-year-old, intensively managed loblolly pine (*Pinus taeda)* and sweetgum (*Liquidambar styraciflua)* plantations and to estimate the N and P contained in that biomass. The cumulative effects of competition control only and competition control, irrigation, fertilization and pest control were investigated on an abandoned peanut field in Decatur County Georgia on a Lakeland sand soil. Planted at 1,157 trees/ha, loblolly pine accumulated 57.3 mg/ha dry biomass 4 years after planting and sweetgum accumulated 26.5 mg/ha dry biomass in the maximum treatment plots. Sweetgum was more responsive to the maximum treatment with a biomass increase of 388 percent compared to a 217 percent increase in loblolly pine biomass. In the maximum treatment plots, loblolly pine accumulated 330 kg N/ha and 35 kg P/ha compared to sweetgum accumulation of 137 kg N/ha and 15 kg P/ha.

INTRODUCTION

In 1994 International Paper Company installed their Forest Growth Maximization Study to determine the potential of highly intensive tree culture on abandoned agricultural land. The most likely motivation for such a study would be to determine the economic feasibility of cultural treatments that are known to increase tree growth. From previous research we know that competition control, soil moisture management, nutrient amendment all increase the growth rate. Pest control also contributes to an increased individual tree growth rate by maintaining the terminal shoots and minimizing defoliation. If the growth response is large enough, these treatments can be made operational over large areas at a cost.

We recognized another opportunity in this study; using plantations of pine or fast-growing hardwoods for tertiary sewage treatments. Land application of secondary treated sewage is not new, but it does require knowledge of how rapidly the applied nutrients can be assimilated into biomass. If the application rate exceeds the assimilation rate, then excess nutrients will not be fixed in biomass and could leave the system by leaching. Our interest in this study was to estimate the N and P fixed into tree biomass that will provide an estimate of the nutrient loading possible without exceeding uptake. Although the design of the experiment is not a land application study, we recognized the potential to derive loading rates. The objective of this research was to estimate the aboveground biomass, N, and P pools of both loblolly pine (*Pinus taeda)* and sweetgum (*Liquidambar styraciflua)* in the control and maximum treatments.

MATERIALS AND METHODS

The field installation was on abandoned agricultural peanut (*Arachis hypogaea)* field in Decatur County Georgia, approximately 16 km southwest of Bainbridge Georgia. The soil was a Lakeland sand (a Typic Quartzipsamment) on International Paper Company's Silver Lake Farm. This installation was a randomized complete block design with three replications of four cumulative treatments. A fourth replication, designated for destructive sampling, contained only the control and maximum treatments. The control treatment consisted of ripping to a 60-cm depth and constant competition control. The irrigation treatment was the control treatment with trickle irrigation of 24 l/day/tree of water pumped from the near-by Silver Lake. The fertigation treatment was the irrigation treatment with the addition of 135 kg N/ha/yr, 33 Kg P/ha/yr and 130 kg K/ha/yr. The maximum treatment was the fertigation treatment with insect pest control, primarily, tip moth (*Rhyacionia frustrana*) for loblolly pine. Each of the complete replications had eight plots; all four treatments with both loblolly pine and sweetgum.

The trees were planted in March 1995 on a 2.4 m X 3.6 m spacing in plots with 12 rows of 18 trees per row.
In December 1998 we systematically selected 40 measurement trees in the center of each plot in replications 1,2, and 3 and 80 trees in replication 4. Diameter outside bark at groundline, breast height, and at the base of live crown was measured with a diameter tape or with calipers. The base of live crown was defined as the base of the lowest live branch on the tree. Distance from the ground to the

[1]Forest Ecologist and Forest Hydrologist, The Belle W. Baruch Institute of Coastal Ecology and Forest Science, P.O. Box 596, Georgetown, South Carolina 29442.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

base of live crown and to the top of the terminal bud was measured with a fiberglass tape attached to a telescoping pole. An observer with an unobstructed view of the terminal bud at approximately a 45 degree angle, determined when the pole tip was level with the top of the terminal bud.
In March 1999 ten randomly selected loblolly pine trees in both the control and maximum plots of Replication 4 were destructively sampled. Diameter at groundline and breast height were measured, the tree was felled by cutting at groundline and the distances to the base of live crown and the top of the terminal bud were measured. Branches were then removed from the bole and both components immediately weighed. Bole and branch sub-samples were taken and weighed. This same procedure was repeated in April 1999 with sweetgum trees in the control and maximum plots of replication 4.

In the laboratory, bole and branch samples were dried at 65 degrees Celsius in a forced-air oven to a constant weight. The bole samples were reweighed and the branch samples were separated into foliage and branches and these components reweighed. Tissue samples were prepared and analyzed for total Kjeldahl N and P by the procedure described in Williams and Gresham (2000). Biomass and nutrient pool sizes were estimated by calculating the average diameter at breast height (dbh) and total tree height by treatment and block. Simple linear regression equations were calculated to predict tree dry foliage weight, branch weight, crown weight, bole weight and total tree weight from dbh squared times total height. Nitrogen and P concentrations of the foliage, branch and bole samples were averaged by treatment for each species and these averages were combined with the biomass estimates to estimate N and P pool sizes on an area basis.

RESULTS

Foliage N and P concentrations were most affected by species and treatment (Table 1). Sweetgum foliage N and P were much higher than for loblolly pine and sweetgum foliage concentrations were much more affected by the maximum treatment compared to loblolly pine. For the branch component, there was little difference in concentrations between sweetgum and loblolly pine in the control treatment and only loblolly pine N showed much maximum treatment response. There was little response to treatment in both sweetgum and loblolly pine bole N and P, and loblolly pine did have more N that did sweetgum.

Loblolly pine was larger and accumulated more N and P compared to sweetgum, but sweetgum was more responsive to the treatments (Table 2). Loblolly pine averaged 13 cm dbh 4 years after planting with the maximum treatment. The 10 cm dbh of trees in the control plots probably reflected an old field effect of residual fertilizer. The total height of loblolly pine in the maximum plots was 7 m compared to 6.1 m for sweetgum. Although much smaller, sweetgum showed an almost 300 percent dbh response to treatment. Sweetgum in the control plots averaged 3 cm dbh and 3 m tall after 4 years with competition control, but without irrigation and fertilization. The height response of sweetgum to treatment was less than the diameter response (206 percent versus 298 percent) but still greater than loblolly pine's response (139 percent). The crown, bole and total aboveground biomass pools (Table 2) reflect the same trends seen in the height and diameter data. After 4 years in the field, loblolly pine produced over 57 mg/ha oven dry, above ground, biomass with the maximum treatment, but only 46 percent was in the bole. Sweetgum in the maximum treatment produced less biomass (27 mg/ha) more bole biomass (60 percent) and was much more responsive to treatment. The bole biomass increased 535 percent and total biomass increased 388 percent comparing the control to maximum treatments.

The distribution of N between species and treatments reflected the biomass differences. Loblolly pine accumulated 330 kg N/ha after 4 years in the field with the maximum treatment compared to 137 kg N/ha for sweetgum. As was the case with biomass, sweetgum N accumulation was more responsive to treatment; crown N increased by 322 percent, bole N increased by 519 percent and total sweetgum N increased by 350 percent. Phosphorus

Table 1—Average (and one standard error) Kjeldahl N and P concentrations (percent) in foliage, branches and boles of 5-year-old loblolly pine and sweetgum trees in plots receiving competition control only (Control) and competition control, irrigation, fertilization, and pest control (Maximum)

Component	Treatment	Species	percent N	percent P
Foliage	Control	Loblolly pine	1.33 (0.03)	0.13 (0.00)
		Sweetgum	2.21 (0.08)	0.26 (0.02)
	Maximum	Loblolly pine	1.40 (0.02)	0.14 (0.00)
		Sweetgum	3.07 (0.08)	0.40 (0.04)
Branch	Control	Loblolly pine	0.44 (0.04)	0.06 (0.01)
		Sweetgum	0.47 (0.03)	0.06 (0.01)
	Maximum	Loblolly pine	0.53 (0.02)	0.06 (0.00)
		Sweetgum	0.44 (0.02)	0.04 (0.00)
Bole	Control	Loblolly pine	0.25 (0.01)	0.03 (0.00)
		Sweetgum	0.19 (0.01)	0.02 (0.00)
	Maximum	Loblolly pine	0.26 (0.01)	0.03 (0.00)
		Sweetgum	0.19 (0.01)	0.02 (0.00)

Table 2—Average (and one standard error) dbh, height, biomass, and N and P accumulation of 5-year-old loblolly pine and sweetgum trees in plots receiving competition control only (Control) and competition control, irrigation, fertilization, and pest control (Maximum)

	Loblolly pine				Sweetgum			
	Control		Maximum		Control		Maximum	
DBH (cm)	9.7	(.1)	13.7	(.1)	3.1	(.3)	9.4	(.3)
Total height (m)	5	(.2)	7	(.1)	3	(.1)	6.1	(.1)
Crown Biomass (kg/ha)	15,216	(470.0)	31,312	(326.0)	3,816	(889.0)	10,552	(803.0)
Bole Biomass (kg/ha)	11,192	(504.0)	26,020	(284.0)	2,983	(598.0)	15,981	(1,153.0)
Total Biomass (kg/ha)	26,410	(974.0)	57,332	(609.0)	6,829	(1,486.0)	26,533	(1,956.0)
Crown N (kg/ha)	143	(4.0)	261	(2.0)	33	(7.0)	107	(13.0)
Bole N (kg/ha)	28	(1.0)	69	(1.0)	6	(1.0)	30	(2.0)
Total N (kg/ha)	171	(6.0)	330	(2.0)	39	(9.0)	37	(15.0)
Crown P (kg/ha)	15	(0.5)	27	(0.2)	4	(1.0)	13	(1.5)
Bole P (kg/ha)	3	(0.1)	8	(0.1)	1	(0.1)	3	(0.2)
Total P (kg/ha)	18	(0.6)	35	(0.3)	5	(1.0)	15	(1.7)

accumulation results are similar to the N results. Loblolly pine accumulated 35 kg P/ha compared to sweetgum's 15 kg P/ha for the maximum treatment.

DISCUSSION

Loblolly pine height growth in the control plots indicates that the estimated site index (25-year base age) would be 60 (Pienaar and Shiver 1980) to 70 (Trousdell and others 1974). Site index for the maximum treatment plots is estimated to be 87 (Pienaar and Shiver 1980).
Sweetgum productivity in the maximum plots exceeded the sycamore (*Platanus occidentalis)* productivity on fertilized plots reported by Steinbeck and Brown (1976). They reported a green weight biomass of 105 Mg/ha after 4 years at a 1.2 by 1.2 m spacing. Assuming a 50 percent dry weight, this is 52 mg/ha at 5.8 times the planting density of our sweetgum that produced 26 mg/ha after 4 years in the field.

One of the reasons for doing this research was to determine the feasibility of slow-rate land application of wastewater on plantations of fast-growing species. Although leaching data are needed to provide a more complete picture, these data provide a useful framework. In the loblolly pine plots receiving the maximum treatment, N was applied at 135 kg/ha/yr and after 4 years 330 kg N/ha was accumulated. The N accumulated in tree biomass is 61 percent of the N applied during that 4-year period. A typical N loading rate for land application would be 3 to 5 kg N/ha/d (Kadlec and Knight 1996) which equates to pumping for 27 to 45 days a year to achieve the 135 kg/ha/yr applied in this experiment. This rough comparison indicates that from 8 to 13 ha will be needed for every ha to receive wastewater if pumping were year around. Another major consideration is whether the site could handle the high hydraulic loading of 208 l/tree/d (Kadlec and Knight 1996) compared to the loading of this study (24 l/tree/d).

CONCLUSIONS

These data present biomass, N and P accumulation rates for fast-growing species and provide several implications for intensive management of loblolly pine and sweetgum. The growth rate of loblolly pine with competition control only indicates that an old-field effect was present. If irrigation and fertilization treatments are added, loblolly pine will grow to 7 m tall and 13 cm dbh after 4 years in the field. At the planting spacing of 1,157 trees/ha loblolly pine can accumulate 57 mg/ha dry biomass. However, sweetgum biomass and nutrient accumulation was much more responsive to the treatment than was loblolly pine. The increase in sweetgum biomass and nutrient accumulation ranged from 267 to 535 percent compared to 181 to 261 percent for loblolly pine. Sweetgum leaves from the maximum treatment had a high N (3 percent) and P (0.4 percent) concentrations and could be used as an organic fertilizer. Finally the treatments did not affect the bole N or P content, but in most cases for branch biomass, N and P was higher in trees from the control plots. We speculate that although the branches and boles did accumulate more nutrients in the maximum plots, the concentration was decreased by the great increase of biomass.

ACKNOWLEDGMENTS

Funding for this study was provided by a grant from the Public Service and Agriculture program at Clemson University. Obviously, this study would not have been possible without the cooperation of International Paper Company that allowed us to sample their field installation.

REFERENCES

Kadlec, R.H.; Knight, R.L. 1996. Treatment wet lands. Boca Raton, FL: CRC Press. 893 p.

Pienaar, L.V.; Shiver, B.D. 1980. Dominant height growth and site index curves for loblolly pine plantations in the Carolina flatwoods. Southern Journal of Applied Forestry. 4: 54-59.

Steinbeck, K.; C.L. Brown. 1976. Yield and utilization of hardwood fiber grown on short rotations. Appplied Polymer Symposium. 28: 393-401.

Trousdell, K.B.; Beck, D.E.; Lloyd, F.T. 1974. Site Index for loblolly pine in the Atlantic coastal plain of the Carolinas and Virginia. Res. Pap. SE-115. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 11p.

Williams, T.M.; Gresham C.A. 2000. Nitrogen accumulation and changes in nitrate leaching after 4 years of intensive forest culture on marginal agricultural land. New Zealand Journal of Forestry Science. 30: 266-279.

INTER- AND INTRA-SPECIFIC DIFFERENCES IN FOLIAR N CONCENTRATIONS OF JUVENILE LOBLOLLY AND SLASH PINE IN NORTH FLORIDA

Yu Xiao, Eric J. Jokela, Tim L. White, and Dudley A. Huber[1]

Abstract—Differences in foliar N concentrations among species, families, and clones may contribute to variation in relative growth performance under varying environmental conditions. Only limited information exists regarding the importance of genetic vs. environmental controls on the nutritional characteristics of loblolly and slash pine. Knowledge of these processes may provide a better understanding of growth strategies among pine taxa and aid in selection and breeding of superior genotypes. This paper will summarize the results of a study designed to investigate the effects of taxa, genotype, site and silvicultural treatments on levels of foliar N concentrations over an entire leaf cycle. Three different pine taxa were investigated (genetically improved loblolly pine, genetically improved slash pine and unimproved slash pine) at two locations in north Florida. Each study consisted of two silvicultural treatments (non-intensive, intensive), three complete blocks within each treatment, three taxa, and 16 open-pollinated families within each taxon. In these juvenile (3-4 yr old) stands, loblolly pine was the most productive species. In comparison to improved and unimproved slash pine, loblolly pine consistently maintained 1) higher foliar N concentrations over time; and 2) higher family variations in N concentrations.

INTRODUCTION

The productivity of loblolly (*Pinus taeda* L.) and slash pine (*P. elliottii* Engelm. var. *elliottii*) stands has been greatly improved since the 1950's. The increases in production are primarily due to the application of intensive silvicultural treatments and the utilization of genetically improved seedlings that offer increased volume gain and disease resistance. Further increases in stand production may result from an improved understanding of how nutritional characteristics vary among species or genotypes in relation to different environments. Several studies, using clones as experimental materials, have also shown that some nutritional traits are under strong genetic control. Forrest and Ovington (1971) reported large differences in foliar nutrient levels (P, Ca, K, Mg, Mn, and Zn) among six clones of radiata pine (*Pinus radiata*). Broad-sense heritabilities among radiata pine clones for foliar nutrients were higher for K, Mg and Ca (Beets and Jokela 1994). Raupach and Nicholls (1982) observed that some nutrients (N, K, Mg, Zn) were significantly different among radiata pine clones in their study. These studies have demonstrated that foliar nutrient levels were controlled by genetic factors, and that nutritional differences were genotype specific. For nutrient use efficiency (amount of dry weight produced per unit weight of nutrients absorbed), Sheppard and Cannell (1985) found 10 - 30 percent differences among 8-year-old clones of *Picea sitchensis* and *Pinus contorta*, which were closely related to the nutrient concentration of foliage. They proposed an ideotype for high nutrient use efficiency as trees having an inherently low nutrient concentrations in needles. Such trees might be well-suited to grow on nutrient poor sites.

From the standpoint of forest genetics, it would be informative to know whether nutritional traits could be incorporated as direct or indirect selection criteria in tree improvement programs to achieve more genetic gain. Additionally, we need to understand if selection on growth traits (DBH, height, and volume) has any indirect effects on the nutrient status of trees. At present, information regarding the genetic architecture (heritabilities, genetic - environmental interaction, and genetic correlation) for the two southern pine species is limited. The objectives of this study were to 1) Examine temporal foliar N dynamics among three southern pine taxa as influenced by site and silvicultural treatments; and 2) Determine the magnitude of variation in foliar N concentrations among families with a taxon.

METHODS

Two field experiments, previously established by the University of Florida's Cooperative Forest Genetics Research program, were sampled in north central Florida (Dunnellon, Levy County, 29°20' N, 82°50' W and Palatka, Putnam County, 29°40' N, 81°42' W). Sixteen open-pollinated families from each of three pine taxa (genetically improved loblolly pine, and improved and unimproved slash pine) were planted at both sites in a five-tree row plot in each of three complete blocks using a split-split plot experimental design. Two levels of silvicultural treatments (intensive vs. non-intensive) were applied. Prior to study establishment, each site was chopped and bedded. Understory vegetation in the intensive silvicultural treatment blocks was controlled during the first growing season

[1]Former Graduate Student, Professor, Professor, and Research Associate, University of Florida School of Forest Resources and Conservation, University of Florida, Gainesville, FL 32611, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

using a combination of mechanical and pre- and post-plant directed spray applications of glyphosate applied at labeled rates. Containerized seedlings were planted in December 1994 at a 5 x 11 ft spacing at Palatka, and a 6 10 ft spacing at Dunnellon. Fertilizers were broadcast applied in the high intensity treatment as a balanced mix of macro- and micronutrients during year 1 (250 lbs/ac DAP + 200 lbs/ac KCl) and year 3 (535 lbs/ac 10-10-10 + micronutrients). Insecticides were applied 3-4 times during the first growing season to control tip moth (*Rhyacionia* spp.) on the high intensity treatment. The low intensity treatment did not receive herbicide, fertilizer or insecticide applications.

Two sample trees within a 5-tree row-plot in each family from each block were randomly selected. Sample trees were healthy and free of disease. In total, 192 sample trees (2 treatments × 3 blocks × 16 families × 2 trees) were chosen for each taxa and site. Overall, 1,152 trees (2 locations × 2 treatments × 3 blocks × 3 taxa × 16 families × 2 trees) were sampled across the two sites. Needle samples were collected eight times over a two-year period from the same branch of every sample tree through the life cycle of the same needle cohort. Approximately 9,216 total leaf samples (2 locations × 2 treatment × 3 blocks × 3 taxa × 16 families × 2 trees × 8 times) were processed for chemical analyses.

Needle N concentrations were measured using the method as outlined in Thomas and others (1967) and Jones and others (1991). Nitrogen concentrations were determined using an Aipkem Flow Solution IV analyzer.

SAS procedures, GLM and MIXED, were used to analyze the data (SAS Institute 1996). Means for foliar N concentrations among the three taxa were compared using the LSMEANS statement in PROC MIXED. A default level of a = 0.05 was used to test significance among the means unless otherwise specified.

RESULTS AND DISCUSSION

Variation of Foliar N Concentrations at the Taxa Level

Nitrogen concentrations generally decreased over a complete leaf life cycle among the three pine taxa (figure 1). Differences in N concentrations were consistent among taxa across locations and treatments, with loblolly pine

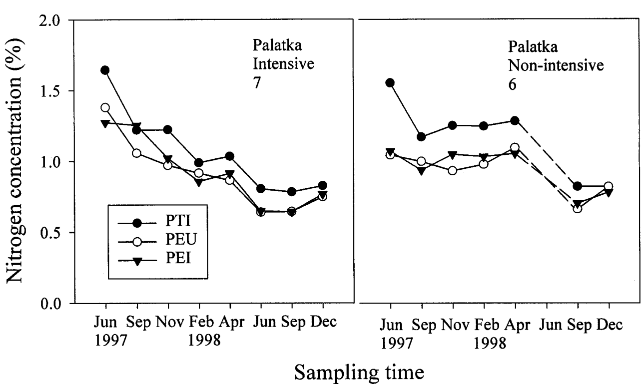


Figure 1—Inter- and Intra-specific Differences in Foliar N concentrations of juvenile loblolly and slash pine in North Florida.

Table 1—Family variation in foliar N concentrations (percent) of the three pine taxa managed under two levels of silvicultural treatments planted at two locations in north-central Florida

Site Treatment Taxa	Interfamily statistics	Mean	Minimum	Maximum
Sampling time: June 1997				
Dunnellon				
High	PTI	1.35	1.02	1.61
	PEU	1.10	0.98	1.20
	PEI	1.21	1.09	1.34
Low	PTI	1.00	0.87	1.12
	PEU	0.90	0.84	0.98
	PEI	0.88	0.73	0.97
Palatka				
High	PTI	1.64	1.38	1.92
	PEU	1.38	1.25	1.47
	PEI	1.28	1.13	1.44
Low	PTI	1.55	1.35	1.80
	PEU	1.05	0.94	1.11
	PEI	1.07	0.98	1.29
Sampling time: December 1998				
Dunnellon				
High	PTI	0.72	0.66	0.77
	PEU	0.74	0.64	0.79
	PEI	0.70	0.64	0.77
Low	PTI	0.81	0.72	0.90
	PEU	0.69	0.63	0.74
	PEI	0.68	0.61	0.74
Palatka				
High	PTI	0.82	0.74	0.91
	PEU	0.75	0.69	0.83
	PEI	0.77	0.68	0.85
Low	PTI	0.82	0.72	0.95
	PEU	0.82	0.74	0.89
	PEI	0.78	0.67	0.90

Note: high = intensive treatment, low = non-intensive treatment; PTI = improved loblolly pine, PEU = unimproved slash pine, PEI = improved slash pine;

having significantly higher concentrations than slash pine. For example, loblolly pine had an average N concentration of 1.64 percent (1.17 and 2.29 percent for minimum and maximum observations, respectively), while improved and unimproved slash pine had N concentrations of 1.28 percent (0.88 - 1.96 percent) and 1.38 percent (1.09 - 1.89 percent), respectively, in June 1997 under the intensive treatment at Palatka. The foliage N concentrations for loblolly pine were significantly higher than either slash pine taxa in seven of the eight sampling periods (88 percent) under the intensive culture treatment and 6 of 8 sampling periods (75 percent) under the non-intensive treatment. Differences in nutrient concentrations for N between improved and unimproved slash pine were generally non-significant. Location × treatment interactions for foliar N concentrations were significant under most sampling periods, showing differential responses among taxa to treatments across locations. Treatments generally did not significantly influence N concentration differences between loblolly and slash pine. Significant treatment × taxa interactions were caused by differential treatment responses between improved and unimproved slash pine, with improved slash pine having lower nutrient concentrations under the non-intensive treatment, but higher concentrations under the intensive treatment compared to unimproved slash pine.

Variation of Foliar N Concentrations at the Family Level

Foliar N concentrations not only showed significant seasonal changes over time at the taxa level, but also varied at the intraspecific (family) level over time (table 1). Family variation in N concentrations (the ratio between the maximum and minimum values of N concentrations) was higher for loblolly than the two slash pine taxa. For example, averaged across locations and treatments, family variation for loblolly, improved and unimproved slash pine was 40, 29, and 19 percent, respectively, in June 1997. Family variation within a taxon decreased from the early fascicle development stage (June 1997) to the later stage (December 1998) for all taxa. Variation in foliar N concentrations among families within a taxon also converged to a similar level for all three taxa. Averaged across locations and treatments, family variation for loblolly, improved and unimproved slash pine was 24, 25, and 20 percent, respectively, in December 1998. The intensive silvicultural treatment increased the foliar N levels at both locations, while loblolly pine still maintained higher N concentrations than the two slash pine taxa across both locations and treatments.

More detailed examination of the relationships between nutrient attributes and growth characteristics at the family level will be helpful to form a better understanding of growth strategies. Estimation of genetic parameters (heritability, genetic-environmental interaction, and genetic correlation coefficients) for various nutritional traits such as nutrient use efficiency, nutrient retranslocation efficiency, and crown nutrient content are planned in the future to quantify the importance of genetic vs. environmental controls on these attributes. Knowledge gained through an understanding of nutritional traits and their relations to growth performance will prove useful in the application of future breeding efforts designed to select superior genotypes for a range of silvicultural management intensities (Xiao 2000).

The potential implications of our findings in the changing nature of foliage N concentrations at the family level suggest that selection could be considered for the two species during the early stages of fascicle development (maturation) if desired in tree improvement programs. For example, N concentrations in the first month that current year foliage attains full length (June, 1997) could be an important sampling period for estimating heritabilities because family variation was most pronounced.

ACKNOWLEDGMENTS

The Forest Biology Research Cooperative at the University of Florida funded this research. Special thanks are extended to Cooperative Forest Genetics Research Program for providing the field sites, and to R.J. English, J. Gagnon, and many students at the School of Forest Resources and Conservation for technical assistance.

REFERENCES

Beets, P.N.; Jokela, E.J. 1994. Upper mid-crown yellowing in *Pinus radiata*: Some genetic and nutritional aspects associated with its occurrence. New Zealand Journal of Forestry Science. 24: 35-50.

Forrest, W.G.; Ovington, J.D. 1971. Variation in dry weight and mineral nutrient content of *Pinus radiata* progeny. Silvae Genetica 20: 174-179.

Jones, JB, Jr.; Wolf, B., Mills, H.A. 1991. Plant Analysis Handbook. Athens, GA: Micro-Macro Publishing, Inc. 213 p.

Raupach, M.; Nicholls, W.P. 1982. Foliar nutrient levels and wood densitometric characteristics in clones of *Pinus radiata* D. Don. Australian Forest Research. 12: 93-103.

SAS Institute. 1996. SAS/STAT software changes and enhancements through release 6.11. Cary, NC, SAS Institute Inc: 1,104 p.

Sheppard L.J.; Cannell, M.G.R. 1985. Nutrient use efficiency of clones of *Picea sitchensis* and *Pinus contorta.* Silvae Genetica. 34: 126-132.

Thomas, R.L.; Sheard, R.W.; Moyer, J.R. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus, and potassium analysis of plant material using a single digestion. Agronomy Journal. 59: 240-243.

Xiao, Y. 2000. Crown structure, growth performance, nutritional characteristics, and their genetic parameter estimates in juvenile loblolly and slash pine. Gainesville, FL: Ph.D. dissertation, University of Florida. 221 p.

ALTERATION OF NUTRIENT STATUS BY MANIPULATION OF COMPOSITION AND DENSITY IN A SHORTLEAF PINE-HARDWOOD STAND

Hal O. Liechty, Valerie L. Sawyer, and Michael G. Shelton[1]

Abstract—Uneven-aged management is used to promote adequate pine reproduction and control species composition of shortleaf pine (*Pinus echinata* Mill.)-hardwood stands in the Interior Highlands of the southern United States. The modification of pine-hardwood composition in these stands has the potential to alter nutrient pools and availability since nutrient uptake, retranslocation, and/or cycling significantly differs in pines and hardwoods. Nutrient status and availability were monitored in a study investigating the effects of different residual pine and hardwood densities on pine reproduction in a mature shortleaf pine-hardwood stand located in the Ouachita Mountains of Arkansas. In 1989 pine basal area was reduced to 13.8 m^2/ha. and hardwood basal area was reduced to 0.0, 3.4, or 6.9 m^2/ha using single-tree selection. A portion of the unaltered stand was used as a control. Nutrient contents of and concentrations in litterfall, forest floor, and soils were monitored 3 and 11 years after harvesting. Nutrient contents and concentrations were then compared among treatments using these data to determine short and long-term changes of nutrient status resulting from the alteration of pine-hardwood composition and density.

INTRODUCTION

Partial cuttings of shortleaf pine (*Pinus echinata* Mill.)-hardwood stands in the Ouachita Mountains are used to regenerate and maintain shortleaf pine as well as to control pine-hardwood composition to meet various wildlife, aesthetic, and diversity objectives. Changes in species composition due to silviculture or natural processes such as succession can alter nutrient regimes, cycling, and availability in forest ecosystems. For example, Alban (1982) compared nutrient levels in soils, forest floor, and litterfall in adjacent 40-year-old plantations of aspen (*Populus tremoloides* Michx.), white spruce (*Picea glauca* Moench), red pine (*Pinus resinosa* Ait.), and jack pine (*Pinus banksiana* Lamb.). Levels of Ca and Mg were generally lower in the soils but higher in the litterfall and forest floor of the aspen than the pine stands (Alban 1982). Binkley and Valentine (1991) found greater accumulations of several base cations and lower net mineralization rates in soils 50 years after an old field was planted to green ash compared to white pine. In the southern United States, Hinesley and others (1991) documented increased nutrient levels in late succession oak-hickory forests compared to early successional pine forests. Switzer and others (1979) found that as old field succession proceeds from pine to oak-hickory communities, soil surface contents of C, N, P, Ca, and Mg increase as does forest floor contents of Ca and Mg. Rates of decomposition nutrient mineralization, or nutrient immobilization are also altered with species composition. Lockaby and others (1995) found that changes in N and P concentration in litter were more dynamic in mixed pine-deciduous stands than in pine-only stands. Decomposition rates appeared to be greater for the mixed stands than pine-only stands (Lockaby and others 1995). Results from these studies suggest that manipulation of the composition of shortleaf pine-hardwoods by partial cutting may potentially alter nutrient cycling and regimes. To better quantify the effects of partial cutting and stand composition on nutrient cycling and regimes, we monitored nutrient concentrations/contents in litterfall, forest floor, and soils 3 and 11 years after application of several uneven-age reproductive cutting prescriptions in a shortleaf pine-hardwood stand. Prescriptions retained 13.8 m^2/ha of overstory pine basal area and 0.0, 3.4, or 6.9 m^2/ha of overstory hardwood basal area. Pine/hardwood composition differed among prescriptions and during the two study periods.

METHODS

Study Site

The study area is located in Perry County Arkansas (34° 52' 12" N Latitude and 92° 49' 30" W Longitude) near Lake Sylvia on the Winona Ranger District of the Ouachita National Forest. Elevations at the site range from 195 to 240 m above mean sea level. Slopes within the study site range from 8 to 21 percent and soils are classified as Typic Hapludults of the Carnasaw and Pirum series and are well drained and moderately deep (Townsend and Williams 1982). Treatment plots were established along an east-west running ridge typical of Ouachita Mountains physiography.

Vegetation in the study area is typical of the Ouachita Mountains where upland forests are dominated by shortleaf pine and mixed oak species (Guldin and others 1994). The site index for shortleaf pine in the study area averaged 17.4 m at 50 years. White oak (*Quercus alba* L.) is the most prevalent hardwood and had an average site index of 16.2 m

[1]Assistant Professor and Graduate Research Assistant, School of Forest Resources, University of Arkansas-Monticello, PO Box 3468, Monticello, AR, 71656; and Research Forester, USDA Forest Service, Southern Research Station, Monticello, AR., 71656, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

at 50 years. Smaller quantities of post oak (*Q. stellata* Wangenh.), black oak (*Q. velutina* Lamarch), blackjack oak (*Q. marilandrica* Muenchh.), and southern red oak (*Q. falcata* Michx.) are present on the site along with ash (*Fraxinus* spp.), hickory (*Carya* spp.), red maple (*Acer rubrum* L.), serviceberry (*Alemanchier arborea* [Michx. f.] Fern.), blackgum (*Nyssa sylvatica* Marsh.), and dogwood (*Cornus florida* L.). Understory vegetation consists mainly of shade tolerant shrubs such as huckleberries (*Vaccinium* spp.) and hawthorns (*Crataegus* spp.) (Shelton and Murphy 1997).

Typical of a number of stands located in the Ouachita Mountains, the stand at the study site developed after intensive harvesting of virgin pine forests in the early twentieth century. Harvesting in the early twentieth century removed high quality pines and oaks with stump diameters of 36 cm or more but left smaller, poorer quality trees (Shelton and Murphy 1991). Establishment of fire suppression during the 1930's resulted in the reestablishment of hardwoods in the understory of these forests. As a result, 90 percent of pines and oaks present prior to the study establishment ranged in age from 50-80 and 40-70 years, respectively (Shelton and Murphy 1991). The youngest age classes found in the overstory for both pines and oaks

Table 1—Mean litterfall and forest floor mass (O_i and O_e) for each harvesting treatment and component in a shortleaf pine-hardwood stand located Perry County, Arkansas

Component	0.0[a]	3.4	6.9	Uncut
	Litterfall Mass (kg/ha) 1991			
Pine Foliage	1,871a[b]	1,481a	1,367a	2,210a
Hardwood Foliage	30c	889b	1,647a	1,361ab
Total Foliage	1,902c	2,370bc	3,014ab	3,571a
Woody Debris	488a	529a	712a	1,017a
Reproductive	287a	274a	444a	387a
Total Litterfall	2,676c	3,173bc	4,171ab	4,975a
	Litterfall Mass (kg/ha) 1999			
Pine Foliage	2,913a	2,580a	2,132a	3,160a
Hardwood Foliage	1,170b	1,744ab	2,480a	1,735ab
Total Foliage	4,083a	4,324a	4,613a	4,896a
Woody Debris	1,528a	1,294a	1,327a	1,576a
Reproductive	628a	669a	730a	619a
Total Litterfall	6,239a	6,287a	6,669a	7,091a
	Forest Floor Mass (kg/ha) 1991			
O_i	7,157a	6,317a	4,939a	5,892a
O_e	14,022a	13,580b	9,150b	12,542ab
Total	21,180a	19,898a	14,090b	18,435ab
	Forest Floor Mass (kg/ha) 1999			
O_i	5,018a	4,802a	4,846a	5,762a
O_e	17,012a	17,963a	18,315a	16,331a
Total	22,031a	22,765a	23,162a	22,094a

[a] Retained hardwood basal area (m²/ha) after harvesting the pine component to 13.8 m²/ha.
[b] Treatments with the same letter for a given component and year are not significantly different at $\alpha = 0.05$.

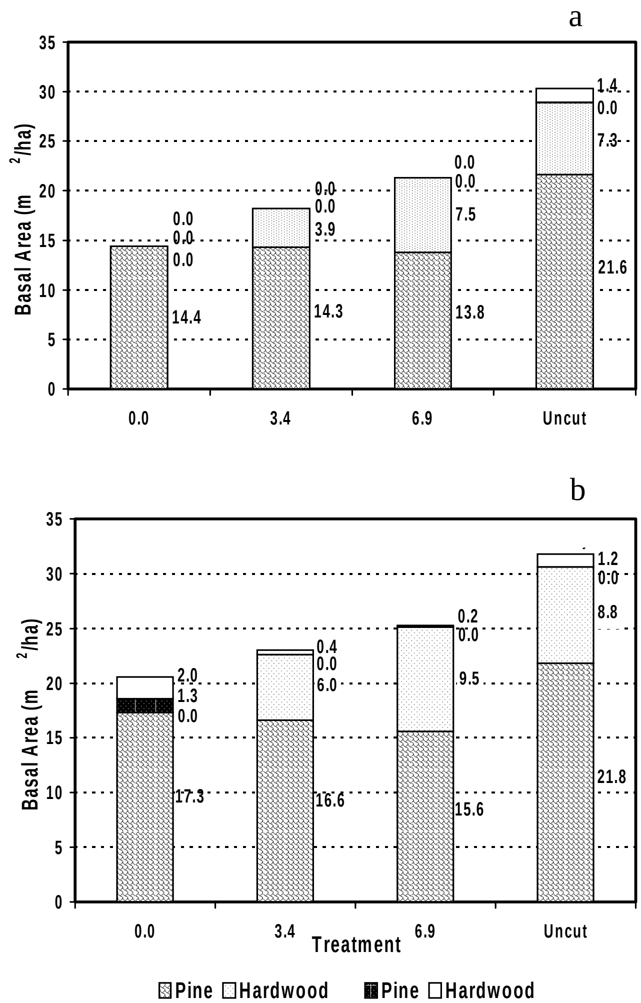
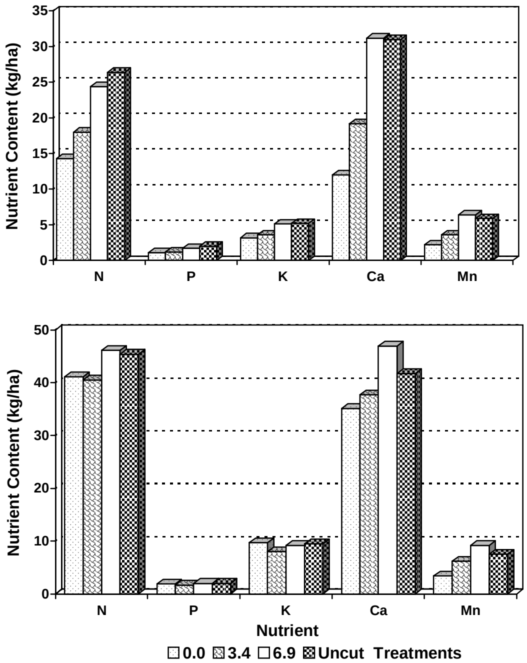


Figure 1—Basal area of pine and hardwood overstory and saplings in a) 1991 and b) 1999 by harvesting treatment (retained hardwood basal area in m²/ha) in a shortleaf pine-hardwood stand located in Perry County, Arkansas.

suggests that regeneration of overstory species had been inhibited 30-40 years prior to the initiation of the study. Average basal areas of shortleaf pine and hardwoods were respectively 21.5 and 6.9 m²/ha prior to harvesting in 1988.

Study Design and Treatment

In late winter of 1988 and spring of 1989, three harvesting treatments were established in four different slope/aspect blocks in a randomized block design. In the three harvested treatments, overstory pine basal area was reduced to 13.8 m²/ha while hardwood basal area was reduced to 0.0, 3.4, or 6.9 m²/ha. Higher quality white and red oaks were retained in a uniform distribution within treatments that maintained residual hardwoods. The basal area-maximum diameter-quotient method of single-tree selection was used to regulate the pine component on each of the harvested treatments (Farrar 1984). The selection targets were 13.8 m²/ha of basal area, 45.7-cm maximum d.b.h., and a 1.2 quotient for 2.5-cm d.b.h. classes. Pine after felling was yarded using mules. No markets were available for the hardwoods, thus all unwanted hardwoods ≥2.5 cm d.b.h.



a

b

Figure 2—Selected nutrient contents of litterfall in a) 1991 and b) 1999 by harvesting treatment (retained hardwood basal area in m²/ha) in a shortleaf pine-hardwood stand located in Perry County, Arkansas. For a given nutrient, treatments with the same letter are not significantly different $\alpha = 0.05$.

were injected with triclopyr amine during April 1989. A 0.2-ha net plot surrounded by a 17.7-m isolation strip was established in each harvesting treatment and block. Net plots were established in a portion of the uncut stands in each block in 1990. The uncut plots have no isolation strip as the surrounding undisturbed stand acts as an isolation strip.

Sample Collection and Preparation

Litterfall was collected on a 1 to 3 month interval for nutrient analysis and mass determination during 1991 and 1999. Litterfall was collected in four 0.08-m² circular traps in each net plot during 1991 and in two additional 0.08-m² circular trap plus three 0.5-m² square traps in each net plot during 1999. All litter was sorted into four components: hardwood foliage, pine foliage, woody debris, and reproductive material. Woody branches and stems greater than 1.25 cm in diameter were excluded from sampling in 1991 while in 1999 only debris greater than 7.50 cm were excluded.

Forest floor was collected on the border of each net plot using three 0.1-m² frames in 1991 and six 0.1-m² frames in 1999. Forest floor samples were separated into the O_i and the O_e horizons. The O_i was further separated into hardwood foliage, pine foliage, woody debris, and reproductive material in 1999. In 1991 samples were not separated by component but the proportion of O_i in each component determined in 1990 was used to estimate component mass from each treatment using total 1991 O_i mass. Maximum branch or stem size included in the samples for 1991 was 2.5 cm and in 1999 was 7.5 cm. Nutrient concentrations for each component for 1991 were determined from the separated samples collected in 1990. Since no sampling was performed in the uncut treatment in 1990, nutrient concentrations for each component in the 6.9-m²/ha treatments were used to estimate the uncut nutrient concentrations.

Mineral soil was collected at the border of the net plot and isolation strip for each plot. In 1991 mineral soil from the 0–15.0 cm depth was collected using a shovel at two locations at the border of the harvested net plots and outside the border of the isolation strips. The samples collected from outside the isolation strips were used as the uncut treatment samples in 1991. Mineral soil was collected from six locations to a depth of 7.5 cm along the border of each net plot using an 8.5 cm impact soil sampler in 1999. Samples were collected from both harvested and uncut control plots.

Litterfall and forest floor samples were dried at 65 °C for at least 48 hours after collection. Samples for each collection period were weighed and then subsamples from each component and type were ground to pass a 1-mm sieve for chemical analysis. Mineral soil was air-dried and passed through a 2-mm sieve. Samples from a given depth, plot, and year were then composited prior to chemical analysis.

Chemical and Statistical Analysis

For litterfall and forest floor samples, P, K, Ca, Mg, S, and micronutrients were determined using inductance coupled plasma (University of Arkansas, Soil Test Laboratory 1990a) after a perchloric acid digestion (Alder and Wilcox 1985). N concentration was determined using micro-Kjeldhal techniques (University of Arkansas, Soil Test Laboratory 1990b). Mineralizable N (Powers 1980), total N, P, K, Ca, Mg, and micronutrients were determined for the mineral soil samples in 1999 but only P, K, Ca, Mg, S, and micronutrients were determined in 1991. P, K, Ca, Mg, S, and micronutrients were determined using inductance coupled plasma (University of Arkansas, Soil Test Laboratory 1992) after a Mehlich 3 soil extraction (Mehlich 1984). N was analyzed using a Skalar autoanalyzer after digestion by Kjeldhal techniques (Bremner 1982).

Analysis of variance was used to evaluate differences in nutrient concentrations, nutrient contents, or mass among treatments. Where differences were significant, Tukey's Honestly Significant Difference test was used to separate treatments means. An a=0.05 was used except where noted.

RESULTS AND DISCUSSION

Litterfall

Three years after harvesting total, total foliage, and hardwood litterfall amounts were significantly lower in the 0.0-m²/ha residual hardwood treatment than in any of the other three treatments (table 1). Generally hardwood foliage, total foliage, and total litterfall amounts reflected differences in basal area and composition among treatments (figure1a). By 1999 the total amounts of litterfall and litterfall foliage did not differ among treatments but the amount of hardwood litterfall was still significantly less in the 0.0-m²/ha treatment than that in the 6.9-m²/ha treatment (table 1). Total and hardwood tree basal area in 1999 still reflected the initial residual densities of the treatments but differences

Table 2—Average forest floor contents and mineral soil concentrations for selected nutrients in each harvesting treatment during 1991 and 1999 in a shortleaf pine-hardwood stand in Perry County, Arkansas

Nutrient	0.0[1]	3.4	6.9	Uncut
Forest Floor Content (kg/ha) 1991				
N	195a[2]	183a	129a	172a
P	13a	11a	9a	12a
K	22a	17a	14a	18a
Ca	194a	148a	145a	181a
Mn	23a	20a	20a	25a
Forest Floor Content (kg/ha) 1999				
N	181a	204a	212a	181a
P	10a	10a	11a	9a
K	11a	13a	16a	13a
Ca	137a	147a	165a	147a
Mn	16b	26ab	32a	28ab
Mineral Soil (mg/kg) 1991[3]				
P	13a	13a	13a	13a
K	48a	42a	30a	44a
Ca	174a	142a	174a	131a
Mn	66a	67a	63a	60a
Mineral Soil (mg/kg) 1999[4]				
Total N	1102a	944a	903a	846a
Mineralizable N	58a	41a	54a	45a
P	4a	4a	5a	4a
K	57a	47a	54a	48a
Ca	246a	98b	119ab	100b
Mn	58a	36a	54a	34a

[1] Retained hardwood basal area (m^2/ha) after harvesting the pine component to 13.8 m^2/ha.
[2] Treatments with the same letter for a given nutrient and year are not significantly different at $\alpha = 0.05$.
[3] 0-15 cm depth.
[4] 0-7.5 cm depth.

were reduced among treatments compared to those observed in 1991 (figure 1). Approximately 3.3 m^2/ha of sapling (1.5-8.9 cm d.b.h.) basal area was present in the 0.0-m^2/ha treatment. The amount of hardwood foliage litterfall collected in the 0.0-m^2/ha treatment during 1999 was 39 times more than that collected during 1991 and reflected the partial recovery of the hardwoods in this treatment. The total amount of litterfall collected in the uncut treatment was respectively 42 percent more in 1999 than 1991. A portion of this increase reflected the larger diameter of woody litterfall included in collections from 1999 ($\leq$7.5 cm) compared to 1991 ($\leq$1.25 cm). However total foliar litterfall also increased by 37 percent during this period. Thus it seams likely that the increased levels of litterfall in 1999 compared to 1991 reflected natural variation in litterfall amounts and the continuing growth of trees in the plots.

Total litterfall nutrient contents in 1991 were generally greatest in the uncut and 6.9-m^2/ha treatments than in the 0.0- or 3.4-m^2/ha treatments (figure 2a). Nutrient contents of litterfall in 1991 closely reflected the differences in the amount of litterfall and basal area among treatments (figure 1; table 1). Removal of pine and hardwoods reduced the inputs of foliage and reproductive material in the litterfall thereby reducing nutrient contents. However, differences in nutrient concentrations of litterfall were evident. Concentrations of Ca and Mn were significantly lower while concentrations of K were significantly higher in the 0.0-m^2 treatment than the uncut and/or the 6.9-m^2/ha treatments. Concentrations in the 0.0-m^2/ha treatment differed from those in the uncut and 6.9-m^2/ha treatment by as much as 30 to 70 percent. These differences were in part related to the changes in the pine/hardwood foliage proportions in the litterfall after applying the harvesting treatments. However, concentrations of K in pine foliage litterfall were also significantly higher in the 0.0-m^2/ha treatment (0.15 percent) than in either the 6.9-m^2/ha treatment (0.11 percent) or uncut (0.11 percent) treatments. These results suggest that harvesting treatments had altered the availability, competition for, or retranslocation of K, Ca, or Mn within these treatments during 1991.

In 1999, 11 years after harvesting treatment application, litterfall nutrient contents generally did not differ among treatments (figure 2b). The similar nutrient levels among treatments reflect the rapid recovery of foliar production in the treatments since harvesting (table 1). Litterfall contents of Mn were still significantly lower in the 0.0-m^2/ha treatment than the uncut or 6.9-m^2/ha treatments. The differences in Mn content are primarily related to the lower concentrations of Mn in the litterfall of the 0.0-m^2/ha treatment. Mn concentrations in the foliar litterfall of the 0.0-m^2/ha treatment (0.10 percent for hardwood and 0.06 percent for pine) were significantly lower than concentrations in the 6.9-m^2/ha treatment (0.17 percent for hardwood and 0.12 percent for pine) and uncut (0.16 percent for hardwood and 0.11 percent for pine) treatment. Mn concentrations in 1991 and 1999 were strongly correlated to the amount of hardwoods retained and basal area harvested. Apparently, reduction of hardwoods alters cycling of Mn by shortleaf pine and hardwoods for a number of years after harvesting.

Forest Floor

Forest floor mass in 1991 was generally the least in the treatments that had little or no hardwood removal, and greatest in treatments that had the greatest hardwood removal. Increased mass of the forest floor in the 0.0- and 3.4-m^2/ha treatments appeared to reflect bark and woody inputs from hardwoods that were killed with herbicide. Eleven years after harvesting in 1999, forest floor mass did not significantly differ among treatments. Recovery of the forest floor mass in the 0.0-m^2/ha treatment was evident, and mass generally varied by less than 10 percent among treatments.

Differences in forest floor nutrient contents among treatments in 1991 were not significant (table 2). However, like forest floor mass, nutrient contents were consistently greatest in the 0.0-m^2/ha treatment. In 1999 differences among treatments were significant for Mn contents but not for N, P, K, or Ca. Differences in forest floor Mn like litterfall can be attributed to lower concentrations of Mn in the 0.0-m^2/ha treatment. Forest floor Mn concentrations were significantly lower in the 0.0-m^2 treatment (0.07 percent) than in the uncut (0.13 percent) or 6.9-m^2/ha treatments

(0.14 percent). Forest floor Mn concentrations were twice as great in the 6.9-m^2 treatment than the 0.0-m^2 treatment. These differences were similar to those observed in the litterfall and generally reflect differences in litterfall Mn concentrations.

Mineral Soil

Mineral soil concentrations with the exception of Ca in 1999 did not significantly differ among treatments (table 2). Frequently, nutrient concentrations were greatest in the 0.0-m^2/ha treatment during 1999, but differences between this treatment and the others were not significant for any nutrient other than Ca. These results suggest that although nutrient cycling may have been altered by the harvesting treatments, this alteration has had minimal impacts on the nutrient levels in the soils in these treatments. It should however be noted that the statistical power of the study design and sampling scheme was lower for the mineral soil component than for either the litterfall or forest floor.

SUMMARY

Changes in stand density and composition due to harvesting treatments significantly impacted the levels of specific nutrients in this study. Impacts were generally greatest in 1991 due to the changes in litterfall and forest floor amounts. However, differences in K and Mn concentrations in litterfall or forest floor altered total amounts of these nutrients in the treatments. By 1999 differences in nutrient contents were minimal among treatments. However, litterfall and forest floor Mn levels in the 0-m^2/ha treatment were still lower than those in the uncut or 6.9-m^2/ha treatments. Any changes in litterfall or forest floor nutrient contents did not appear to alter nutrient concentrations in soils. Concentrations of nutrients did not significantly differ among treatments either 3 or 11 years after harvesting.

ACKNOWLEDGEMENTS

This work was jointly supported by the Arkansas Forest Resources Center and the Southern Research Station.

REFERENCES

Alban, D.H. 1982. Effects of nutrient accumulation by aspen, spruce, and pine on soil properties. Soil Science Society of America Journal. 46: 853-861.

Alder, P.R.; Wilcox, G.E. 1985. Rapid perchloric acid digest methods for analysis of major elements in plant tissue. Communication in Soil Science and Plant Analysis. 16: 1153-1163.

Binkley, D.; Valentine, D. 1991. Fifty-year biogeochemical effects of green ash, white pine, and Norway spruce in a replicated experiment. Forest Ecology and Management. 40: 13-25.

Bremner, J.M. 1996. Nitrogen-Total. In Sparks, D.L. Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A. Johnson, C.T., and Sumner, M.E. (ed). Methods of soil analysis. Part 3. Soil Science Society of America Book Series, 5: 595-624.

Farrar, R.M. 1984. Schnur's site index curves formulated for computer applications. Southern Journal of Applied Forestry. 9: 3-5.

Guldin, J.M.; Baker, J.B.; Shelton, M.G. 1994. Midstory and overstory plants in mature pine/hardwood stands of the Oucahita/Ozark forests. In: Baker, J.B., comp. Proceedings of the symposium on ecosystem management research in the Ouachita Mountains: pretreatment conditions and preliminary finding. 1993 October 26-27. Hot Springs, AR. Gen. Tech. Rep. SO-112. New Orleans, LA: U.S. Department of Agriculture Forest Service; Southern Forest Experiment Station: 29-49.

Hinesley, L.E.; Nelson, L.E.; Switzer, G.L. 1991. Weight and nutrient content of litter during secondary succession on well-drained uplands of the East Gulf Coastal Plain in Mississippi. Canadian Journal of Forest Research. 21: 848-857.

Lockaby, B.G.; Miller, J.H.; Clawson, R.G. 1995. Influences of community composition on biogeochemistry of loblolly pine (*Pinus taeda*) systems. American Midland Naturalist. 134: 176-184.

Mehlich, A. 1984. Mehlich 3 soil extractant: A modification of Mehlich 2 extractant. Communications in Soil Science and Plant Analysis. 15: 1409-1416.

Powers, R.F. 1980. Mineralizable soil nitrogen index of nitrogen availability to forest trees. Soil Science Society American Journal. 44: 1314-1320.

Shelton, M.G.; Murphy, P.A. 1991. Age and size structure of a shortleaf pine-oak stand in the Ouachita Mountains: Implications for uneven-aged management. In: Coleman, S.S.; Neary, D.G., comps. Proceedings of the sixth biennial southern silvicultural research conference. 1990 October 30-November 1. Memphis, TN. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station: 67-72.

Shelton, M.D.; Murphy, P.A. 1997. Understory vegetation 3 years after implementing uneven-aged silviculture in a shortleaf pine-oak stand. Res. Pap. SO-296. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 13 p.

Switzer, G.L.; Shelton, M.G.; Nelson L.E. 1979. Successional development of the forest floor and soil surface on upland sites of the East Gulf Coastal Plain. Ecology. 60: 1162-1171.

Townsend, W.R.; Williams, L. 1982. Soil survey of Perry County, Arkansas. Washington, DC: U.S. Department of Agriculture Soil Conservation Service and Forest Service; Fayetteville, AR: Arkansas Agricultural Experiment Station. 113 p. + maps.

University of Arkansas, Soil Test Laboratory. 1990a. Procedure No. PL-0003: Total plant tissue digest-ICAP analysis for Ca, Mg, Na, K, Fe, Mn, Zn, Cu, P, S, and B. Fayetteville, AR: University of Arkansas, Soil Test Laboratory. 3 p.

University of Arkansas, Soil Test Laboratory. 1990b. Procedure No. PL-0004: Plant tissue total nitrogen analysis. Fayetteville, AR: University of Arkansas, Soil Test Laboratory. 3 p.

University of Arkansas, Soil Test Laboratory. 1992. Procedure No. SO-0001: Soil-ICAP analysis for Ca, Mg, Na, K, Fe, Mn, Zn, Cu, P, S, and B. Fayetteville, AR: University of Arkansas, Soil Test Laboratory. 3 p.

EFFECT OF A ONE-TIME BIOSOLIDS APPLICATION IN AN OLD-FIELD LOBLOLLY PINE PLANTATION ON DIAMETER DISTRIBUTIONS, VOLUME PER ACRE, AND VALUE PER ACRE

E. David Dickens[1]

Abstract—A forest land application of biosolids study was initiated in 1991 in the lower Coastal Plain of South Carolina (SC). A major objective of this project was to quantify the magnitude and duration of old-field loblolly pine (*Pinus taeda*, L.) growth response to a one-time biosolids application after canopy closure. The study area is located on Alcoa property in Berkeley County, SC. The soil series, Goldsboro (Fine-loamy, Aquic Paleudults) was delineated by a NRCS soil mapper in a 1982 planted loblolly pine stand. Gross treated and interior permanent measurement plots were installed in a randomized complete block design. Forty feet of untreated buffer was maintained between plots. All living loblolly pines were tagged, numbered, and measured for dbh and total height in February-March 1992. Berkeley County Water and Sanitation Authority (BCW&SA) biosolids (5.7 percent total-N, 15 percent solids, extended aeration treated) were applied one-time in April 1992 at 0, 650, and 1300 pounds of total-N per acre (5.7 and 11.4 dry tons/acre). The stand was operationally thinned (third row with logger select in between) in August 1993 reducing SPA from 560 to 300 (BA/ac from 120 to 65 square feet). Stand data from age 10-years-old to age 17-years-old show a dramatic growth increase in mean dbh increment (0.5 and 1.0 inch), total height increment (2.0 and 2.7 feet), volume/tree (30-35 percent), and volume/acre increment (37-38 percent) in the biosolids versus the control plots. Diameter distributions 7 years after biosolids application favored more chip and saw (8-9 cords/acre) and less pulpwood (1-3 cords/acre) in the biosolids versus control plots. Total wood value/acre was increased by $555 to $595 (at $19/cd pulpwood and $73/cd chip and saw (Timber Mart-South 2000) in the biosolids plots versus the control plots by age 17-years-old.

INTRODUCTION

Total demand for forest products is anticipated to increase substantially by the year 2030 (USDA 1988). Pulpwood is projected to show the largest rise, with demand increasing 50 percent (GFC 2001). The southeastern US is estimated to produce 50 percent or more of the world's pulp and paper 30 years from now (USDA 1988). This increased demand for wood fiber coincides with the recent interest by the US congress and EPA to promote beneficial use of biosolids. Forest land application of biosolids can save large sums of money through landfill tipping fee cost avoidance and extensions in landfill life. These savings are estimated for South Carolina to range from $50,000 to $400,000 per year per county. Loblolly pine (*Pinus taeda,* L.), a principle southeastern US crop tree, will often respond to one-time N+P fertilization on most better drained Coastal Plain soils (NCSUFNC 1999). Forest wood and fiber products are not a part of the human food chain and forest land application scheduling and management is not as complicated as in other crop alternatives. There is an abundance of forest land in South Carolina where two-thirds of 19 million acres is forested (Tansley and Hutchins 1988).

METHODOLOGY

Permanent measurement plots were established in the fall of 1991 on Alcoa property in Berkeley County, SC. The study area was on an old field 10-year-old loblolly pine planted at 6x10 feet with 14 feet between every 5th row. The soil series throughout the study area was Goldsboro. The experimental design was randomized complete block with two replications (blocks) per treatment (0, 5.7, and 11.4 dry tons biosolids/acre) in the loblolly pine stand for a total of six experimental units (plots). Gross treated plots averaged 1/4 acre and internal permanent measurement plots averaged 1/10th acre. Forty feet of untreated buffer was maintained between each plot. Plot conversion factors were used to convert from volume per tree and number of trees to wood volume per acre for each plot and biosolids treatment. All living loblolly pine trees in each plot were affixed with a numbered aluminum tree tag at 4.5 feet above groundline then measured for diameter (Dbh with a d-tape) and total height (height pole except the last measurement was with a clinometer) in February-March 1992 prior to biosolids application and two (1/94), four (1/96), five (3/97), and seven (3/99) growing seasons after biosolids application. Extended aeration biosolids (80 percent domestic and 20 percent industry input, 15 percent solids, 5.7 percent total-N, table 1) were applied on 9-15 April 1992 at 0, 5.7 dry tons (200 PAN) and 11.4 dry tons

[1]Assistant Professor - Forest Productivity, Warnell School of Forest Resources - University of Georgia, P.O. Box 8112 GSU, Statesboro, GA 30460.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Concentrations and application levels for the BCW&SA biosolids applied to an old-field loblolly pine plantation in Berkeley County, SC on a Goldsboro soil

---------------Component--------------------		-----------Application Level-----------------	
	Concentration	Low	High
	--mg/kg dry basis--	-----------kg/ha (lb/ac) dry basis-----------	
Biosolids		2800 (11400)	25,500 (22800)
Kjeldahl-N	57000	728 (650)	1460 (1300)
NH_4-N	1660	21.1 (18.9)	42.3 (37.8)
NO_3-N	53	0.67 (.60)	1.3 (1.2)
elemental-P	11500	147 (131)	293 (262)
elemental-K	3770	48.2 (43)	96 (86)
Ca	18600	237 (212)	475 (424)
Mg	6400	81.8 (73)	164 (146)
As	3.0	0.038 (.034)	0.076 (.068)
Cr	10.0	0.128 (.114)	0.260 (.230)
Cu	380	4.85 (4.33)	9.70 (8.66)
Pb	33	0.421 (.376)	0.842 (.752)
Ni	38	0.476 (.433)	0.970 (.866)
Se	1.7	0.022 (.020)	0.045 (.400)
Zn	500	6.4 (5.7)	12.8 (11.4)

(400 PAN) per acre to randomly assigned plots. Plant available nitrogen (PAN) was estimated to be 30 percent of organic-N (TKN - NH_4-N), 50 percent of NH_4-N, and 100 percent of NO_3-N (SC-DHEC 1996). The low biosolids level (5.7 dry tons/acre or 38 wet tons/acre) was achieved by one pass with a tractor and pull behind side port spreader at a known speed with the port door set to a marked opening height and the PTO RPMs set at 540. Two passes achieved an average of 11.4 dry tons/acre (76 wet tons/acre). Fourteen feet between every fifth row allowed for ground access into the plots. The stand was operationally thinned (third row with logger select in between) in August 1993 from an average of 560 stems/acre (120 ft^2 BA/ac) to 300 SPA (65 ft^2 BA/ac). Winter prescribe backing fires were performed in the entire study area in February 1994, 1996, and 1998.

An analysis of covariance (SAS 1988) was run on 1994 data to ensure that a “common” starting point among the treatment levels after the thinning. Per acre basal area was used as the co-variate but it was not significant nor was the treatment effect. There were no significant treatment differences (5 percent alpha level) for mean dbh, total height, total volume/tree and total volume/acre the 1994 data. The number of stems in each diameter class was multiplied by the plot conversion factor to obtain the number of trees/acre by dbh class. Pre-thinning and pre-treatment (3/94) average stems/acre were 589 for the control, 555 for the low biosolids (200 PAN/ac) and 527 for the high biosolids (400 PAN/ac). Post thinning (1/94) stems/acre averages were 310 for the control, 300 for the low biosolids (200 PAN/ac) and 286 for the high biosolids (400 PAN/ac). Age 17-years-old average stems/acre were 297 for the control, 295 for the low biosolids (200 PAN/ac) and 271 for the high biosolids (400 PAN/ac). Diameter distributions at age 17-years-old were discerned by individual measured stems in one inch dbh classes from 4.0 - 4.9 to 12.0 and greater. The stem volume equations used (Pienaar and Grider 1984, Bailey and others, 1985) were:

$$TV_{(ib)} = 0.0014793\ D^{1.821}H^{1.1629}$$
$$MV_{(ib)} = TV_{(ib)}(1 - 0.4482\ D_m^{3.4580}D^{-3.1947})$$

where

$TV_{(ib)}$ = inside bark, total stem volume in cubic feet
$MV_{(ib)}$ = inside bark, merchantable stem volume in cubic feet
D = dbh in inches
H = total stem height in feet
D_m = outside bark, merchantable diameter in inches.

It was assumed that 100 percent of the tagged loblolly pines were pulpwood after biosolids application (age 10-years-old) and after the thinning (age 12-years-old). Product class distribution (either pulpwood or chip and saw) at age 17-years-old was estimated in the following manner. All living tagged loblolly pines in each plot that were 9.0 inches dbh and over were considered to be chip and saw trees. All living tagged trees that were 4.0 through 8.9 inches dbh were considered to be pulpwood trees. Where dbh was greater than or equal to 9.0 inches then D_m was 4.0 inches. Where dbh was less than 9.0 inches then D_m was 2.0 inches. Each individual measured living stem was therefore “merchandised” into either a “pulpwood” or “chip and saw” tree at age 17-years-old. Seventy-six cubic feet (ib) per cord was used as the conversion factor. A price of $19/cord for pulpwood and $73/cord for chip and saw

Table 2—Mean diameter (at 4.5 feet above groundline), total height, volume/tree (ib), and volume/acre in a 1982 planted old-field loblolly pine plantation where biosolids were applied (4/92) in Berkeley County, SC on the Goldsboro soil series

Year	Trt[a]	Dbh (in)	Tot Ht (ft)	Vol/tree (ft^3)	Vol/acre (ft^3)
1992	Control	5.05	26.7	1.29	760
	Low	5.33	27.2	1.45	805
	High	4.88	26.6	1.20	632
1994	Control	6.44	39.2	3.13	970
	Low	6.74	39.0	3.38	1014
	High	6.45	38.0	3.11	889
1996	Control	7.22	43.8	4.39	1317
	Low	7.69	45.4	5.13	1513
	High	7.54	43.8	4.75	1287
1997	Control	7.63	48.5	5.47	1625
	Low	8.17	49.5	6.34	1870
	High	8.12	49.2	6.22	1686
1999	Control	8.01	51.8	6.44	1913
	Low	8.82	54.3	8.12	2395
	High	8.83	54.4	8.15	2209
Culm.	Control	2.96	25.1	5.15	1153
grow	Low	3.49	27.1	6.67	1590
92-99	High	3.95	27.8	6.95	1577

[a]Treatments = biosolids treatments: control (no treatment), low (200 lb PAN/acre), and high (400 lb PAN/acre). The stand was operationally 3rd row thinned with select in between in August 1993 from 120 BA/acre to 65 ft^2 BA/acre.

(Timber Mart-South 2000) was used to determine value/ace by product class and total value/acre by treatment.

RESULTS

Loblolly pine mean diameters in the 1982 established stand were 4.88 inches (400 lb PAN/ac), 5.05 inches (control), and 5.33 inches (200 lb PAN/ac) in March 1992 prior to biosolids application and 8.01, 8.82, and 8.83 inches, respectively by March 1999 (table 2). Control plots mean diameter increased 2.96 inches, the 200 lb PAN/acre plots mean diameter increased 3.49 inches, and the 400 lb PAN/acre mean diameter increased 3.95 inches during the seven year measurement period. Average seven year diameter increment was increased by .07 and .14 inches/year in the biosolids plot trees compared to the control plot trees (table 2). Five year (94-99 post thin) average loblolly pine dbh increment was 0.314"/yr for the control, 0.416"/yr for the 200 PAN/acre, and 0.476"/yr for the 400 PAN/acre treatment.

Average loblolly pine tree heights prior to biosolids application were 26.7, 27.2, and 26.6 feet for the control, 200, and 400 lb PAN/acre plots, respectively at age 10-years-old (table 2). Average total heights seven years after biosolids application (3/99) were 51.8, 54.3, and 54.4 feet for the control, 200, and 400 lb PAN/acre plots, respectively. Average tree height growth during this seven year period since biosolids application was 25.1, 27.1, and 27.8 feet for the control, 200, and 400 lb PAN/acre plots, respectively. Biosolids plots height increment was 8 percent and 11 percent above the control seven years since biosolids application (table 2). Five year (94-99 post thin) average loblolly pine height increment was 2.52'/yr for the control, 3.06'/yr for the 200 PAN/acre, and 3.28'/yr for the 400 PAN/acre treatment.

Total inside bark wood volume per tree means prior to biosolids application (age 10-years-old) were 1.29, 145, and 1.20 cubic feet (inside bark) for the control, 200, and 400 lb PAN/acre plots, respectively (table 2). Wood volume per tree averages seven years after application (3/99) were 6.44 (control), 8.12 (200 lb PAN/acre), and 8.15 (400 lb PAN/acre) cubic feet. Wood volume per tree growth between 1992 and 1999 was 5.15 (control), 6.67 (200 lb PAN/acre), and 6.95 (400 lb PAN/acre) cubic feet. The biosolids plots mean wood volume per tree growth during the seven years since biosolids application was 30 percent (200 lb PAN/acre) and 35 percent (400 lb PAN/acre) greater than the control's. Five year (94-99 post thin) average loblolly pine volume/tree increment for the 200 and 400 PAN/acre biosolids treatments were 43 percent and 52 percent greater than the control, respectively. Post thin average annual volume/tree increment was 0.662 ft^3/yr for the control, 0.948 ft^3/yr for the 200 PAN/acre, and 1.01 ft^3/yr for the 400 PAN/acre treatment.

Total inside bark wood volume/acre means were 760, 805, and 632 cubic feet for the control, 200 PAN/ac, and 400 PAN/ac plots, respectively, prior to biosolids application

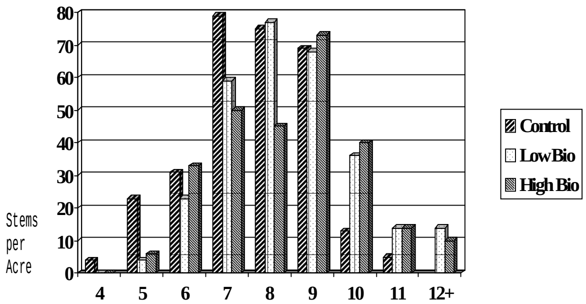


Figure 1—Old-field thinned loblolly pine plantation diameter distributions by treatment seven years after a one-time biosolids application in Berkeley County, SC on a Goldsboro soil series.

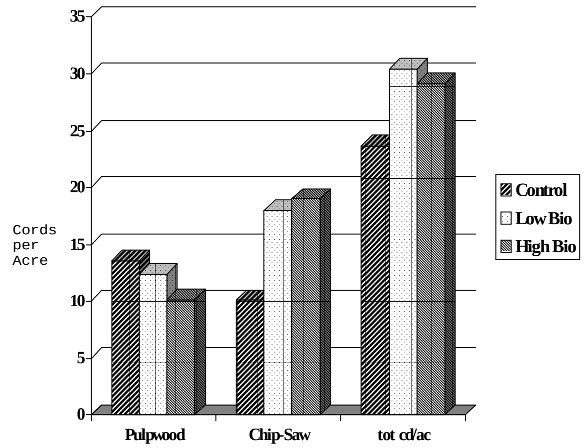


Figure 2—Old-field thinned loblolly pine plantation mean cords per acre production by treatment seven years after a one-time biosolids application in Berkeley County, SC on a Goldsboro soil series.

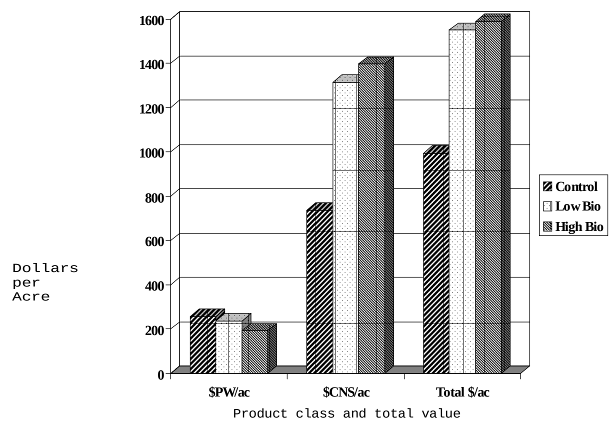


Figure 3—Old-field thinned loblolly pine plantation mean value by product class and per acre by treatment seven years after a one-time biosolids application in Berkeley County, SC on a Goldsboro soil series.

(3/92). Total inside bark wood volume means were 1913, 2395, and 2209 cubic feet for the control, 200 PAN/ac and 400 PAN/ac, respectively, seven years after the one-time biosolids application and five years after the thinning. Total wood volume(ib)/acre growth was 1153 (control), 1590 (200 PAN/ac), and 1577 (400 PAN/ac) seven years after biosolids application or 37-38 percent more wood volume increment in the biosolids plots. Five year (94-99 post thin) average loblolly pine volume/acre.year increment was 189 ft^3/yr for the control, 276 ft^3/yr for the 200 PAN/acre, and 264 ft^3/yr for the 400 PAN/acre treatment. Post thin average loblolly pine volume/acre for the 200 and 400 PAN/acre biosolids treatments were 46 percent and 40 percent greater than the control, respectively.

Diameter distributions in the low and high biosolids plots favored more chip and saw sized trees (9.0 inch dbh or greater) and less pulpwood sized trees (< 9.0 inch dbh) by age 17-years-old compared to the control plot diameter distribution (figure 1). Product class merchantable volumes in the biosolids plots had 8-9 more cords/acre in the chip and saw category and 1-3 cords/acre less pulpwood by age 17-years-old (figure 2). The pulpwood dollar value was greater in the control plots by $22 and $65 per acre compared to the low and high biosolids plots by age 17-years-old (figure 3). Chip and saw dollar value was $577 and $660 greater in the low and high biosolids plots, respectively, compared to the control seven years after treatment (figure 3). The net total revenue increase in the biosolids plots was $555 and $595 compared the the control plot mean (@ $19/cord for pulpwood and $73/cord for chip and saw) for the extra wood grown by product class. The internal rate of return ($(\text{Return/cost})^{1/7}-1$) for the extra wood grown over seven years at a cost of $90/acre for one pass (the low biosolids level) and $180/acre for two passes (the high biosolids level) is 29.7 percent and 18.6 percent for the low and high biosolids treatment.

DISCUSSION

The literature is scarce documenting the magnitude and duration of response to biosolids when applied to old-field planted loblolly pine stands. Loblolly pine dbh, total height, volume per tree, and volume per acre biosolids plots means were greater than the control seven years after the one-time biosolids application (table 2). Biosolids plots wood volume per tree and volume/acre seven year increments were 30-35 percent and 37-38 percent greater than the control, respectively. Diameter distributions in the biosolids plots favored 8-9 cords more chip and saw and 1-3 cords less pulpwood by age 17-years-old. In this old-field trial the extra wood volume gain due to biosolids application was greater than 5 cords/acre. Dollar revenues were increased by an average of $575/acre in the biosolids plots seven years after application and five years after a thinning in the 1982 planted loblolly pine stand. Using a typical DAP+Urea fertilizer plus application cost of $90/acre for the one pass to achieve the 200 PAN/acre biosolids level and the extra $555 in wood grown over 7 years, the calculated rate of return was 29.7 percent. Assuming a cost of $180/acre for two passes to achieve the 400 PAN/acre biosolids level and the $595/acre extra wood grown, the calculated rate of return is 18.6 percent. The incremental growth gain (4 percent wood volume seven year increment increase over the low biosolids) and $40 extra dollars/acre generated in wood value from the high biosolids (two passes to achieve 76 wet tons/acre) in this case does not appear to be worth the extra time, cost, and labor compared the one pass low biosolids one-time application level.

The 200 pounds of plant available nitrogen (PAN) per acre biosolids application level is in line with the current nitrogen prescription (200 N+ 25-50 lbs P/acre) for loblolly pine stands after canopy closure (NCSUFNC 1999). This 200 PAN/acre application level includes 131 lbs elemental-P, 43 lbs elemental-K, 212 lbs Ca, 73 lbs Mg, 4.33 lbs Cu/acre and organic matter. Loblolly pine foliar N, P, and K were above sufficiency (1.2 percent N, 0.12 percent P, and 0.35 percent K) in all plots prior to biosolids (1992) application. Foliar levels of N and P by 1996 in the control plots were below sufficiency while the biosolids plot foliar levels were still above sufficiency. Top soil (0-2") soil organic matter was 2.5 percent in the control plots, 4.1 percent to 5.7 percent in the biosolids plots in 1997. Mehlich I soil P (0-6") was < 8 ppm in the control plots and 20-95 ppm in the biosolids plots in 1997.

Berkeley County, SC is over 77 percent forested with approximately 550,000 acres wooded (Tansley and Hutchins 1988). Thousands of acres of privately owned loblolly pine plantations are in close proximity to the Berkeley County Water and Sanitation Authority treatment plant. Using 1992 BCW&SA biosolids generation figures and the low application level (5.7 dry tons/acre) approximately 500 acres of land would be needed per year. If the biosolids are to be applied once every 7-10 years (in conjunction with a thinning regime) then 3,500 to 5,000 acres are needed for a seven to ten year cycle in near-by loblolly pine stands after canopy closure (with access) or just after a thinning.

CONCLUSIONS

Land application of BCW&SA biosolids in established loblolly pine plantations in Berkeley County, SC proved beneficial, increasing wood volume growth increment by 37-38 percent and value by $555 to $595 per acre seven years after application. A second objective in this study area was to determine the effect of the one-time biosolids application on local groundwater quality. Four year data showed no adverse effect of the one-time biosolids application on groundwater quality (Dickens and others 1997, Dickens 1999). Realistically, the low biosolids level (5.7 dry tons/acre or an estimated 200 lbs PAN/acre) achieved in one pass proved almost as beneficial in seven year wood volume growth, dollar acre increased revenue, and may be the closer to the amount of N needed for loblolly pine growth at this age class compared to the two pass high biosolids level (11.4 dry tons/acre or an estimated 400 lbs PAN/acre).

ACKNOWLEDGMENTS

The author would like to thank Alcoa, Berkeley County Water and Sanitation Authority, and Engineering Resources Corporation for supporting this project.

REFERENCES

Bailey, R.L.; Grider, G.L; Rheney, J.W.; Pienaar, L.V. 1985. Stand structure and yields for site-prepared loblolly pine plantations in the Piedmont and Upper Coastal Plain of Alabama, Georgia, and South Carolina. UGA Res. Bull. 328. School of Forest Resources, Athens, GA: University of Georgia. 117p.

Dickens, E.D. 1999. Determination of an environmentally sound one-time biosolids application in loblolly pine plantations of South Carolina. Pap. 992179. In: Proceedings of the ASAE annual international meeting; 1999 July 18-21; Toronto, Canada.

Dickens, E.D.; R.K. White; and R. Jones. 1997. Effects of forest land application of biosolids on local groundwater in the Coastal Plain of South Carolina. In: Proceedings of the annual residuals and biosolids management conference; 1997 August 3-6; Philadelphia: WEF 12 p.

GFC. 2001. Georgia Forestry. Spring 2001 edition. 23 p.

NCSUFNC. 1999. NCS Forest Nutrition Cooperative - 28th annual report. June 1999. Dept. of Forestry College of Forest Resources, NCSU. Raleigh, NC. 28 p.

Pienaar, L.V. and G.E. Grider. 1984. Standard volume and weight equations for site-prepared loblolly pine plantations in the Piedmont of South Carolina, Georgia, and Alabama. UGA PMRC Res. Paper 1984-3. School of Forest Resources, UGA, Athens, GA. 13 p.

SAS Institute Inc. 1988. SAS/ETS user's guide. Version 6. First Edition. Cary, NC: SAS Institute Inc. 560 p.

SC-DHEC. 1996. Beneficial use of wastewater biosolids - SC guide on land application of wastewater sludge. SC Dept of Health and Environ. Control, Columbia, SC: 50 p.

Tansley, J.B. and C.C. Hutchins, Jr. 1988. South Carolina's forests. SEFES Res. Bull. SE-103: U.S. Department of Agriculture, Forest Service. 96p.

Timber Mart South. 2000. Timber Mart-South 2nd Qrtr. Vol. 25 No. 2. SC 2nd qrtr stumpage prices. Athens, GA: Daniel B. Warnell School of Forest Resources, UGA.

U.S. Department of Agriculture. 1988. The South's fourth forest: alternatives for the future. Forest Resource Report 24: Wash., D.C. 512 p.

NITRATE LEACHING FROM INTENSIVE FOREST MANAGEMENT ON ABANDONED AGRICULTURAL LAND: FIFTH-YEAR RESULTS

Thomas M. Williams, Charles A. Gresham[1]

Abstract—This report is on the fifth year results of a cooperative research project to examine water quality impacts of maximizing plantation growth on abandoned agricultural land, first reported after two years in the Ninth Southern Silvicultural Research Conference. The study, located on International Paper's Southland Experimental Forest at Bainbridge GA, examines growth of loblolly pine (*Pinus taeda* L.) and sweet gum (*Liquidambar styraciflua* L.) with complete vegetation control, irrigation, fertilization, and pest control as a factorial experiment on an abandoned agricultural field. Groundwater quality was measured in the maximum (all combined) and minimum (only vegetation control), the old field without plantation management, natural forest, and along the shore of Silver Lake. After two years groundwater nitrate concentrations in all the plots in the abandoned field violated drinking water standards (> 10mgN/l) and were significantly higher than the natural forest or lake edge. Soil moisture nitrate was significantly higher in the plots with vegetation control. After five years the number of violations and maximum nitrate concentrations have declined by roughly 50%. Soil moisture nitrate concentrations have declined significantly in the plantation plots in the last three years, at shallow depths. Concentrations at the five foot depth below the minimum treatment plots approached that found in the natural pine < 0.5mgNO_3-N /l. Growth rates have been large in all treatments except the sweet gum minimum treatment. Irrigated loblolly plots have accumulated over 250 kgN/ha from the soil pool in the abandoned field. The nitrogen pools within the soil have been sufficient to continue nitrate leaching for five years and supply 200-300 kg N/ha to the control and irrigated (only) pines.

INTRODUCTION

This paper updates a study first presented in the Ninth Southern Silvicultural Symposium (Williams 1999). The study has been following nitrate leaching on an abandoned peanut (*Arachis hypogaea* L.) field which has been used to grow loblolly pine and sweet gum at accelerated rates. International Paper has installed an experiment to examine highly intensive culture on marginal agricultural land on their Silver Lake experimental area near Bainbridge,GA. In this experiment three replications of four treatments have been applied to sweet gum and loblolly pine. The treatments are: complete competition control, plus irrigation, plus fertigation, plus fertigation and pest control for the maximum treatment. The goal of our section of this project was to evaluate the potential for contamination of groundwater or the adjacent Silver Lake. Groundwater and soil moisture were sampled from five locations in each replication: maximum treatment, minimum treatment, field with no treatment, adjacent natural pine stand, and hardwoods at the edge of Silver Lake. These plots were located as a transect from treated plots downhill to the lake.

Data collected during the first two years of the project confirmed that the direction of subsurface flow was not from the experimental area to the lake. However, the data also clearly showed high concentrations of nitrate nitrogen (NO3-N) beneath the entire old field. Groundwater concentrations peaks were over 27 mg NO3-N/ liter and exceeded EPA drinking water in all points below the field regardless of treatment. All groundwater NO3-N concentrations were significantly (> 10fold) higher than found in the natural forest plots. During the first year the minimum treatment concentration was significantly higher than the old field but this difference disappeared during the second year. Soil moisture NO3-N concentrations were significantly higher in the intensive treatments than in the fallow field and both were also 10 fold higher than the adjacent natural forest.

At that time, the best explanation of the results was tied to decomposition of peanut residues since they had been shown to rapidly release nitrogen (Smith and Sharpley 1990). Also, the higher soil moisture concentrations were thought to be associated with competition control which has been associated with other studies with higher NO3-N concentrations (Likens and others 1969, Munson and others 1993, Neary and others 1986).

[1]Thomas M. Williams, Charles A. Gresham, Belle W. Baruch Institute of Coastal Ecology and Forest Science, PO Box 956, Georgetown, SC 29442, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

The study has been followed through the fifth growing season. During that period soil moisture and groundwater nitrate has been measured on a quarterly basis. In addition, trees and the forest floor have been measured for biomass and nitrogen uptake. The major questions to be answered have been: 1). Will nitrate leaching continue to be a problem? 2). Does plantation management have a significant impact on nitrogen cycling on the abandoned field?

METHODS

The study was done at International Paper's Silver Lake Experimental Forest near Bainbridge, GA on a former peanut field near the shore of Silver Lake. Silver Lake is a small stream valley that flooded subsequent to creation of Lake Seminole by a dam on the nearby Flint River. Soils of the site are Lakeland (Typic Quartzipsamments) and Eunola (Aquic Hapludult). In the old field, soils are excessively well drained fine sand to loamy sand.

The plantation management experiment is laid out as three replicates of a randomized block, 2x4 factorial experiment. Factors are species (loblolly and sweet gum) and management intensity (control, irrigation, irrigation + fertilizer, and irrigation + fertilizer + pest control). Since all the blocks had herbaceous competition control and genetically improved seedlings, the controls were still rather intensive cultural treatments.

Soil Moisture and Groundwater Sampling

Soil moisture and groundwater were examined using multi-level soil moisture and groundwater samplers on three transects, one from each replicate. Each transect consisted of five plots: Minimum treatment(control defined above), Maximum treatment, old field outside of the treatment plots, within a 50 year-old pine stand surrounding the field, and at the edge of the lake. In each replicate, the five plots were aligned perpendicular to the land slope from the field to the lake edge.

In April 1995 a 15 cm diameter hole was augured below the water table and a 5 cm PVC well screen was placed 60 to 120 cm below the water table at each sample location. All plots, except the lake edge, had water tables at approximately 6 meters depth and auger holes were 7 to 7.5 m deep. Horizontal drilling was used to place four (2.5 cm x 10 cm long) tension lysimeters in undisturbed soil approximately 30 cm from the central shaft. Tension lysimeters were connected to sample bottles in a box on the soil surface, and all sample bottles were connected to a central vacuum manifold.

Trees were planted in February 1995 and cultural treatments were begun in April 1995. Sampling of soil moisture and groundwater was begun in May 1995 and samples were collected twice each month until December 1996.

Tension lysimeters were maintained at tensions between 0.5 and 0.7 bar continuously throughout the period. At each sampling, water was poured from the lysimeter sample bottles into 60 ml polyethylene bottles, all 5 cm wells were pumped until clear and a 60 ml sample was collected.

Sampling was discontinued in December 1996 and was resumed in November 1997 and the sampling frequency was reduced. From November 1997 through December 1999 quarterly sampling was done. Groundwater was sampled three times and soil moisture was sampled twice each quarter. At the first visit during the quarter, a groundwater sample would be taken from all the wells. At that time the vacuum pump would be started and 0.5 to 0.7 bar tension would be placed on all of the lysimeters. After each of the next two rains the site would be revisited and samples taken from all wells and lysimeters. During the last visit the pump would be turned off until the first visit in the next quarter.

All samples were placed in coolers and returned to the Baruch Institute Lab in Georgetown SC and nitrate determinations were made within 24 hours. Nitrate analyses were done using cadmium reduction technique on a Technicon autoanalyser (Greenberg and others 1992).

Biomass and Nitrogen Content Sampling

Trees were planted in rows 3.7 m apart and spaced at 2.4 m within rows and each treatment plot consisted of 12 rows with 18 trees per row. A border 7.3 m wide was established in each plot using the inner 80 trees as a measurement plot. Forty of these were uniformly chosen by skipping every other tree on each row within the measurement plot. Tree growth was measured on three treatments: minimum, irrigated, and maximum, for each replication. For each tree, measurements were basal diameter, diameter at breast height, diameter at base of live crown, height of live crown, and total height. All measures were taken in January of 2000.

Biomass and nutrient accumulation were determined for the maximum and minimum treatments. In addition, the irrigation treatment was also sampled for nutrient content. Twenty trees of each species were sampled to determine biomass-size equations. A fourth replication of the maximum and minimum treatments of both species was designated for destructive sampling. Ten trees of each species from the maximum plot and 10 from the minimum plot were harvested, separated into: stems, dead branches, unfoliated branches, and foliated branches, and were weighed green. Subsamples were dried (60ºC) and weighed to obtain moisture content; subsamples of foliated branches were separated into branches and leaves before drying. Dry weight proportions from subsamples were used to determine dry weight of trees in the following components: stem, dead branches, live unfoliated branches, foliated branches, and leaves. Portions of each subsample were subsequently ground for nutrient analysis.

To assure that all trees measured during the fifth growing season were within the range of trees sampled for biomass, biomass equations were calculated on trees collected after the sixth growing season. Sweet gum trees were collected in September 2000 while loblolly were collected in February of 2001.

Forest floor biomass was estimated on the maximum, irrigated, and minimum plots for each species. In June 2000, all litter (humus layers had not yet formed in any treatment) was removed from 14, 1 m2 areas on a transect extending diagonally across each measurement plot as described above. Plots were stratified into rows (1 m on each side of the tree centers) and inter-rows (greater than 1 m from either row center). Seven areas were collected from each row and inter-row. All litter was carefully scraped from the soil surface and placed into paper bags. Bags were dried (60ºC) and weighed. Subsamples of each bag were ground for nutrient analysis.

All dried subsamples were ground to pass a 1.0mm sieve. The bole samples were chipped prior to grinding in the Wiley mill. Ground materials were Kjeldahl digested (Isaac and Johnson 1976, Labconco 1987, Jones and Case 1990, Jones 1991), diluted with DDW and colorimetrically analyzed for nitrogen and phosphorus with a Technicon AutoAnalyzer II using Industrial Method No. 329-74W/B (Nov. 78 revision) (Technicon Industrial Systems 1978). The nitrogen analysis method uses the sensitive color reaction between NH4+ and alkaline sodium salicylate with a chlorine source (Crooke and Simpson 1971, Technicon Industrial Systems 1978, Nelson and Sommers 1980). Averaged nutrient concentrations were then multiplied by biomass estimates to estimate nutrient quantities.

Statistical Analysis

Statistical analyses of the groundwater samples were as repeated samples of five treatments and three blocks. On the lake edge no tension lysimeters were installed, since the water table was so close to the surface. Soil moisture samples were analyzed as repeated samples of a factorial with four treatments, four depths, and three blocks. Treatment differences in groundwater within each year were tested by the Tukey multiple range test. Soil moisture concentration comparisons were made between years at a particular depth and across depths within a particular year. These analyses were also tested by Tukey multiple range tests.

Simple linear regressions were calculated for each component and total biomass. Equations were based on the same measures as taken in the growth plots. These regressions were combined with the growth data collected on each treatment to estimate treatment biomass means.

Loblolly equations were:

Bole	
biomass= 0.00958 D2h + 7.47	Rsq = .887
Dead Branch= 0.00372 D2h - 3.71	Rsq = .832
Unfoliated Branches= 0.076 BaBlc -1.82	Rsq = .624
Foliated Branches=0.0245 BaBlc -1.084	Rsq = .374
Leaves= 0.00401 BaBlc X Llc + 2.871	Rsq= .406
Total Biomass= 0.018 D2H + 14.62	Rsq = .926

Where biomass is in kilograms, D is diameter at breast height in cm, h is total height in m, Bablc is the basal area at the base of the live crown cm^2, Llc is length of live crown in m and is total height – height of live crown.

Sweet Gum equations were:

Bole= 0.0195 D2h + 1.53	Rsq = 0.96
Dead Branch= 2.1888 Hlc - 0.1892	Rsq = 0.86
Unfoliated Branch= 0.677 D - 2.47163	Rsq = 0.64
Foliated Branch= .00517 (BaBlc x Llc)+ 0.652	Rsq = 0.65
Leaves= 0.3026 BD - 1.4787	Rsq = 0.82
Total Biomass= 0.0305 D2h + 0.9581	Rsq = 0.96

Where units are as defined above and BD is basal diameter in cm and Hlc is height of live crown in m.

Tree part and total biomass were calculated by applying the above equations to each tree measured in the three measurement replication. Average values were then calculated from the aggregated measurements and expressed on a per hectare basis assuming full stocking (1125 t/ha). Nitrogen accumulation was taken by multiplying the appropriate nitrogen content to each tree part and calculation an average tree N content and expressed as per hectare values in the same way.

RESULTS

Groundwater nitrate nitrogen concentrations are the most important of this study in that NO3-N concentrations above 10 mg/l are above drinking water standards. Concentrations measured above this value represent contamination of the groundwater. Table 1 presents groundwater concentrations for each treatment during the five years on measurement.

Table 1—Nitrate-nitrogen concentrations in shallow groundwater for each year of measurement. Average concentration during each year followed by the same letter are not significantly different (α = .05). Maximum concentrations in excess of 10 mg NO3-N/l are violations of EPA drinking water standard.

Average Concentrations mg NO3-N/l					
	1995	1996	1997	1998	1999
Lake Edge	0.26a	0.34a	0.04a	0.04a	0.02a
Forest	0.40a	0.24a	0.17a	0.15a	0.09a
Field	2.46ab	5.46b	5.41b	5.09b	3.43ab
Maximum	4.82bc	6.60b	6.18b	6.47b	7.57b
Minimum	6.62c	8.82b	6.92b	7.42b	8.09b
Maximum Concentrations mg NO3-N/l					
Lake Edge	0.44	1.40	0.07	0.09	0.07
Forest	1.48	4.36	0.48	0.36	0.22
Field	8.49	10.67	7.75	12.48	6.86
Maximum	13.93	27.89	9.90	15.98	10.84
Minimum	19.93	17.99	9.64	17.89	13.84

The table clearly shows that nitrate nitrogen leaching has continued in the field throughout the five years. There have been violations of the drinking water standard throughout the period also. One must regard the 1997 data with caution since it represents the fall period only during that year and fall samples showed lowest concentrations in all years. With that in mind there has been a decline in the maximum concentrations during the last two years. If this trend is real and continues drinking water violations may cease by year six or seven.

Soil moisture data shows patterns much more clearly than the groundwater data. Since the field was on a Lakeland sand the water table was in excess of six meters below the surface. Impacts of the treatments would most likely first appear at the soil surface and would be expected in the upper soil moisture before the groundwater.

Soil moisture NO3-N concentrations showed considerable variability in both time and space (table 2). Averaged over all depths the forest plot had significantly lower concentrations than the other treatments. There were no significant differences between the other treatments when all depths were considered. In the old field treatment there have been no significant trends in soil moisture NO3-N concentrations. However, there have been significant trends in soil moisture NO3-N concentrations in both the minimum and maximum treatment (table 2). In both treatments there has been a trend toward lower concentrations in the upper soil during the last two years. In 1997 there were fewer data and analyses between depths were not possible. However, at 1.5 meters both the maximum and minimum treatments showed significantly lower concentrations than during the previous years. At this depth the minimum treatment concentrations have remained significantly lower in 1998 and 1999. Also, during 1998 and 1999 the 1.5m depth has also had significantly lower concentrations than deeper depths on the same treatment. During these years the concentration at the 1.5 m depth has been in the same range as the forest treatment. The maximum treatment shows similar trends but the differences were not significant until 1999. Also the reduction in concentration on the maximum treatment appears to extend to the 3 meter depth.

Table 2—Soil moisture Nitrate – Nitrogen Concentrations (mg NO3-N/l) by depth and year. Within each treatment values followed by the same upper case letter are not significantly different between years within depths. Values with the same lower case letter are not significantly different between depths within years. (α = .05)

Depth (m)	1995	1996	1997	1998	1999
Forest Treatment*					
1.5	0.82	0.30	0.08	0.25	0.02
3.0	0.12	0.15	0.01	0.36	1.06
4.6	0.51	0.43	0.17	0.20	0.05
Old Field Treatment*					
1,5	3.70	8.93	2.95	6.33	2.13
3.0	7.13	5.24	3.96	4.32	1.24
4.6	4.56	8.67	5.84	3.70	8.74
6.1	4.98	5.85	7.80	4.02	6.09
Maximum Treatment					
1.5	11.12aA	10.75aA	2.808	5.46bA	0.96bB
3.0	9.50aA	6.53aA	8.60A	2.77bB	4.43abA
4.6	11.333A	14.43aA	6.12A	9.63aA	9.02BA
6.1	9.488A	14.22aA	8.07A	0.98aA	4.01abA
Minimum Treatment					
1.5	9.88aA	10.51aA	0.798	0.23cB	0.26bB
3.0	11.54aA	10.32aA	5.45A	6.37bA	9.39aA
4.6	12.97aA	13.39aA	11.01A	12.61aA	9.42aA
6.1	6.43aA	10.57aA	6.89bA	10.69aA	

* No significant differences between depths or years.

Nitrogen Uptake

During the five years that leaching has been measured the plantations have been growing at very high rates (table 3). Loblolly pine has been much more effective during the first five years in accumulation of both biomass and nitrogen. On the irrigated and minimum treatments these growth rates have been supplied entirely from nitrogen within the old field soil. The loblolly irrigated treatment has been the most effective in accumulating nitrogen form the field soil. The loblolly minimum treatment has accumulated nearly as much. The old field soil contained sufficient nitrogen to sustain rapid growth and accumulation of 173 kgN/ha and continue to show groundwater nitrate-nitrogen concentrations of 8.1 mg NO3-N/l.

The lowered NO3-N concentrations in the upper profile might indicate that uptake is beginning to deplete nitrogen reserves. Data now leaf nitrogen content may also tend to support that view. In table 4 leaf nitrogen contents in the fourth and fifth growing seasons are compared to those measured during the first and second (Samuelson 1998) when soil moisture NO3-N concentrations were uniformly near 10 mg/l. The data in table 4 are has some limitations in that Samuelson (1998) collected leaves in August while the fourth year leaves were collected in May and the fifth in June. McNeil and others (1988) found that loblolly pine

Table 3— Summary of fifth year growth on measurement plots in maximum growth study. Biomass and nitrogen are expressed assuming 1125 t/ha. Biomass represents only above ground living tree parts but total nitrogen includes nitrogen measured in the forest floor.

Treatment	Height	DBH	Total Biomass	Total Nitrogen
	m	cm	Mg/ha	kg/ha
Loblolly Maximum	8.63	15.6	72.7	282.8
Loblolly Irrigated	7.64	13.8	57.8	207.2
Loblolly Minimum	6.42	11.5	46.0	178.3
Sweet Gum Maximum	8.18	11.1	49.9	153.2
Sweet Gum Irrigated	6.16	7.6	22.5	66.9
Sweet Gum Minimum	4.29	4.7	10.4	43.3

needle nutrient content decreases as needles age suggesting that the leaves collected in May and June would be expected to have higher nitrogen content than those collected in August.

Although there was a clear decline in soil moisture NO3-N concentration in the control plots during the third year there were no declines in leaf nitrogen content until the fifth. During the fifth year the nitrogen content of both species in the minimum treatments are considerably lower than during the first four. The decline is larger in the irrigated treatments. This result would be expected since the irrigated treatments are growing considerably faster with the same soil nitrogen pool. The growth and leaf nitrogen data are consistent with the soil moisture NO3-N concentrations.

SUMMARY

After five years of growth the old field in this study continues to exhibit nitrate leaching. Groundwater NO3-N concentrations are significantly higher in all treatments in the old field than in the adjacent natural pine forest and the hardwoods along the lake edge. Groundwater NO3-N concentrations also continue to have peak values above 10 mg NO3-N/l in all of the old field treatments.

Soil moisture NO3-N concentrations do show significant changes after five years. The surface (1.5m) lysimeters in the minimum treatment shown a significant (both by year at that depth, and by depth within the last three years) declines. Concentrations are below 0.5 mg NO3-N/l and very similar to the surface concentrations found in the natural hardwoods.

Growth rates and nitrogen accumulation have been very rapid during the five years, with accumulations over 200 kgN/ha on sites receiving no fertilization. Leaf nitrogen content declines in the minimum treatment are consistent with depletion of the nitrogen pool within the surface soil. However, the nitrogen pool has been large enough to support accumulation of 173 kgN/ha and produce groundwater NO3-N concentrations that averaged 7.5 mg NO3-N/l for the entire five year period.

Table 4—Leaf nitrogen content of loblolly needles and sweet gum leaves on experimental plots during the first and second (Samuelson 1998) and fourth and fifth growing seasons. Nitrogen content of leaves (percent)*

Treatment	1995	1996	1998	1999
Loblolly Maximum	1.47	1.42	1.39	1.46
Loblolly Irrigated	1.22	1.28	1.20	1.03
Loblolly Minimum	1.10	1.28	1.31	1.09
Sweet Gum Maximum	2.17	2.60	3.13	2.01
Sweet Gum Irrigated	2.09	2.29	2.21	1.11
Sweet Gum Minimum	1.92	2.07	2.21	1.41

* First and second year leaves were collected in August, fourth year in late May, and fifth year in June

ACKNOWLEDGMENTS

This project has been supported by a US Forest Service, Southern Research Station and South Carolina Agricultural Experiment Station. International Paper provided access, cooperation, and logistical support throughout the experiment. Special thanks to Tom Cooksey for all his help on the project. Thanks also go to L. Wayne Inabinette , Lowanda Jolley, Steven Knoche, Carrie Lucas, Mike Gibson, and Steven Morris for help in the field and laboratory.

REFERENCES

Crooke, W.M.; Simpson, W.E. 1971. Determination of ammonium in Kjeldahl digests of crops by an automated procedure. J. of Sci. Fd. Agric. 22: 9-10.

Greenberg, A.E.; Clesceri, L.S.; Eaton, A.D. 1992. Standard methods for the examination of water and wastewater, 18th ed. Wash. DC: American Public Health Association.

Issac, R.A.; Johnson, W.C. 1976. Determination of total nitrogen in plant tissue, using a block digester. Journal of the Association of Official Analytic Chemists 59(1): 98-100.

Jones, J.B. 1991. Kjeldahl Method for Nitrogen Determination. Athens, GA: Micro-Macro Publishing, 79 p.

Jones, J.B. Jr.; Case, V.W. 1990. Sampling, handling and analyzing plant tissue samples. In: Westerman, R. L., ed., Soil Testing and Plant Analysis, Third Edition, Soil Science Society of America Book Series, no. 3. 784 p: 389- 427.

LABCONCO 1987. Rapid Kjeldahl methodology for the determination of nitrogen in feeds, foods, grains, cereals, and grasses. Kansas City, MO: Labconco Corporation.

Likens, G.E., F.H. Borrmann, N.M. Johnson. 1969. Nitrification: importance to nutrient losses from a cutover forested ecosystem. Science 163: 1205-1206.

McNiel, R.C,; Lea, R.; Ballard, R.; Allen, H.L.1988. Predicting fertilizer response of loblolly pine using foliar and needle-fall nutirents sampled in different seasons. Forest Science 34: 698-707.

Munson, A.D.; Margolis, H.A.; Brand, D.G. 1993. Intensive silviculture treatment: Impacts on soil fertility and planted conifer response. Soil Science Society America Journal 57: 246-255.

Neary, D.G.; Bush, P.B.; Douglass, J.E. 1986. Water quality in ephemeral streams after site preparation with the herbicide hexazinone. Forest Ecology and Management. 14: 23-40.

Nelson, D. W.; Sommers, L. E.1980. Total Nitrogen analysis of soil and plant tissues. Journal of the Association of Analytic Chemists 63(4): 770-778.

Samuelson, L.J. 1998. Influence of intensive culture on leaf net photosynthesis and growth of sweet gum and loblolly pine seedlings. Forest Science 44: 306-316.

Smith, S.J.; Sharpley, A.N 1990. Soil nitrogen mineralization in the presence of surface and incorporated crop residues. Agronomy Journal. 82: 112-116.

TECHNICON INDUSTRIAL SYSTEMS. 1978. Individual/ simultaneous determination of nitrogen and/or phosphorus in BD acid digests. Tarrytown, NY: Technicon Industrial Systems. 9 p.

DETERMINING NUTRIENT REQUIREMENTS FOR INTENSIVELY MANAGED LOBLOLLY PINE STANDS USING THE SSAND (SOIL SUPPLY AND NUTRIENT DEMAND) MODEL

Hector G. Adegbidi, Nicholas B. Comerford, Hua Li, Eric J. Jokela, and Nairam F. Barros[1]

Abstract—Nutrient management represents a central component of intensive silvicultural systems that are designed to increase forest productivity in southern pine stands. Forest soils throughout the South are generally infertile, and fertilizers may be applied one or more times over the course of a rotation. Diagnostic techniques, such as foliar analysis and soil testing are available, yet have not been highly successful in identifying fertilizer responsive sites. In most cases recommendations, based on these approaches, lack site-specificity. The Soil Supply And Nutrient Demand (SSAND) model is a mechanistic computer simulation model developed to: (1) diagnose nutrition limitations and (2) determine site-specific fertilization regimes necessary to achieve preset production goals. With this model, the user sets a desired level of production and the model is used to calculate stand nutrient demand. Using mass/flow diffusion theory, the model then simulates the soil supply and compares it to the demand. If the demand is more than supply, fertilization regimes can be tested in order to see which may be the most efficient in meeting plant nutrient demand. This paper provides an overview of the SSAND model and its application.

INTRODUCTION

Forest productivity of southern pine plantations is well below their biological potential (Farnum and others 1983, Neary and others 1990a), and low soil fertility is one of the major constraints to their potential being realized (Neary and others 1990b). It is not surprising, therefore, that during the last two decades genetic improvement, competition control, and water and nutrient management have increased productivity (Colbert and others 1990, Jokela and Martin 2000, Neary and others 1990a,b, Prichett and Comerford 1982).

Current fertilization recommendations are based on soil testing, foliar analysis, and field trials. However, recommendations lack site-specificity, which is most likely due to the empirical nature of these techniques. Consequently, a process-based assessment of the nutrient requirements of southern pine plantations and the bioavailability of soil nutrients are required. The Soil Supply And Nutrient Demand (SSAND) model is a process-based computer simulation model that combines the processes controlling nutrient uptake by plants and nutrient supply by soil in order to diagnose the depth of a nutrition limitation and to determine a site-specific fertilization regime. This paper provides an overview of the model and presents examples of how it is used.

MODEL STRUCTURE AND FUNCTIONS

SSAND is written in Microsoft Visual Basic 6.0, using Microsoft Excel worksheets and text files as inputs. Output is provided in *.txt files and Excel worksheets. Figure 1 shows the main interface of SSAND and the four steps that it performs.

Step 1. Desired Plant Growth

The user chooses the species of interest and inputs the production goal, called Desired Plant Growth. The Desired Plant Growth is provided, by the user, via an Excel worksheet and can be specified as biomass growth data over time (biomass input file; figure 2a). A second input file documents nutrient use efficiency (NUE) for producing the biomass over time (figure 2b). These input files are used to compute and generate a file of the nutrient demand necessary to achieve the production goal. Figure 3 shows an example of the output of nutrient demand with time.

Step 2. Nutrient Uptake Model

This step computes the soil supply and nutrient uptake by the plant using mass flow/diffusion theory for soil processes and root characteristics as the soil boundary condition definition. The model uses soil parameters (soil volume, bulk density, water content, nutrient diffusion coefficient in water, mineralization rate, and nutrient adsorption-desorption isotherm characteristics; figure 4a) and plant parameters (rate of water flux into roots, the

[1] Post-doctoral Research Associate; Professor, School of Forest Resources and Conservation, University of Florida, P.O. Box 110410 Gainesville, FL 32611; Professor, Soil and Water Science Department, University of Florida, P.O. Box 110290, Gainesville, FL 32611; Computer Specialist, Internet & Multimedia Systems, Sarnoff Corporation, CN 5300, Princeton, NJ 08543-5300; Professor Titular, Departamento dos Solos, Universidade Federal de Viçosa, Viçosa, Minas Gerais, Brazil, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

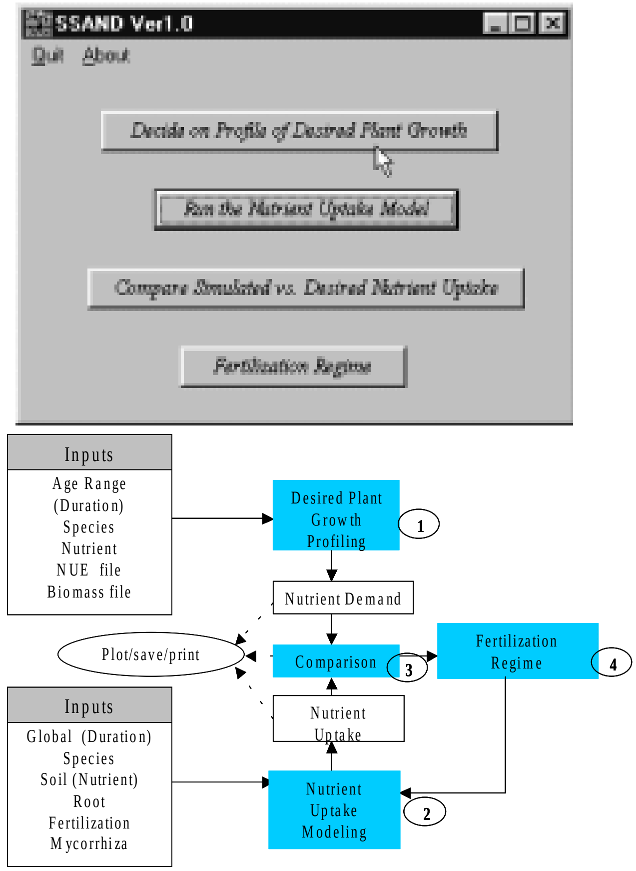


Figure 1—The SSAND model's main interface and structure.

average fine root radius, the root length density and nutrient uptake kinetics parameters; figure 4b) to evaluate the processes responsible for plant nutrient uptake by roots. Additional features allow the user to simulate nutrient uptake by extramatrical mycorrhizal fungi or the roots of a second, competing plant species, or both. The output from this step is the predicted nutrient uptake for which an example is found in figure 5.

Step 3. Comparison of Predicted Uptake and Demand

The third step compares the predicted nutrient uptake to the nutrient demand over time, as well as a user-defined limit around the result. If the predicted uptake is above or within the user-defined limit, the interpretation is that nutrient bioavailability is not a limitation to the desired productivity. If the uptake is below the user-defined limit of the uptake/demand curve, then the nutrient demand may be limiting productivity and fertilization should be useful. Such a nutrient limitation, beginning after 250 days, is shown in figure 6.

Step 4. Fertilization Regime

This fourth step allows the user to design a fertilization regime using multiple fertilization events. Each fertilization event is defined by the day of fertilization and the amount of elemental nutrient applied as fertilizer (figure 7a). A fertilization regime can have as many events as desired.

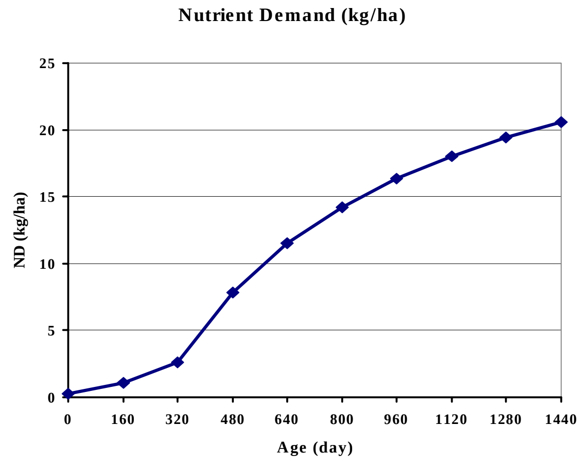


Figure 3—An example of the nutrient demand profile required to achieve predetermined production goals.

Final Modeling Outcome

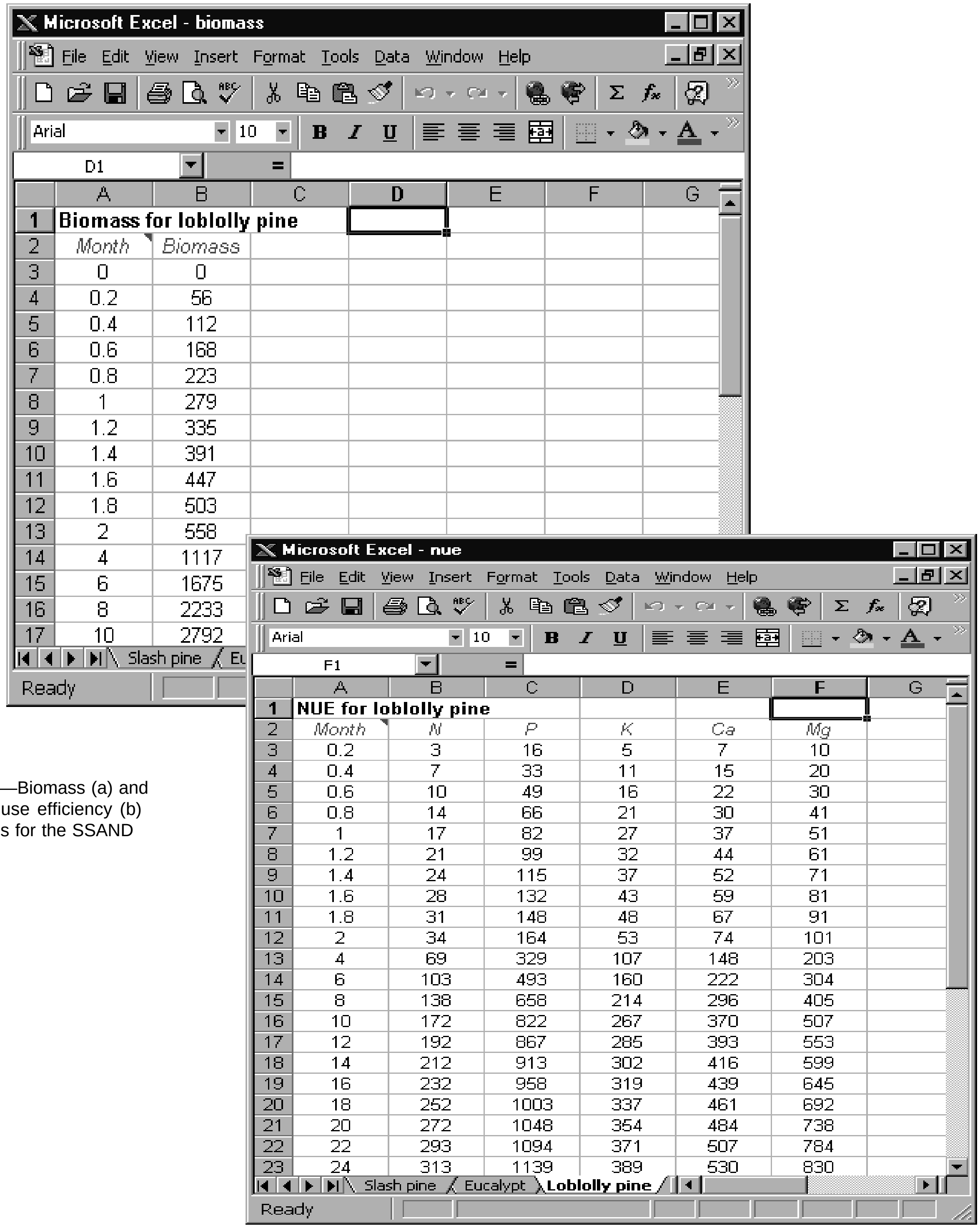
After inputing a fertilization regime, the nutrient uptake model (step 2) is run again and a new comparison is made between nutrient uptake and demand (step 3). The user can iteratively and interactively try various fertilization regimes until the predicted uptake meets the demand of the desired production. The example in figure 7b shows a fertilization regime that supplies the plant demand necessary to achieve the predetermined production goal.

TESTING AND VALIDATING THE SSAND MODEL

A process-based model requires detailed inputs from which the necessary processes can be simulated. Required data include:

- Temporal curves of total plant biomass for the desired level of production
- Nutrient concentrations of tree biomass components (including roots) and temporal curves of nutrient use efficiency
- Soil bulk density
- Water content changes by horizon over time
- Nutrient mineralization rates
- Fine root and/or mycorrhizal fungi characteristics (average fine-root radius by horizon, root length density by horizon, average water influx rate to roots by horizon, nutrient uptake kinetic parameters)
- Adsorption and desorption isotherms by horizon

During the past two years, our efforts have focused on acquiring the biomass, fine root data, plant tissue nutrient data and soil chemical and physical data necessary to test this model in intensively managed, juvenile (age 1 through 4) stands of loblolly pine growing on Spodosols of the Coastal Plain of southeastern Georgia. Above- and belowground components of 104 trees were harvested and



Microsoft Excel - biomass

Biomass for loblolly pine

Month	Biomass
0	0
0.2	56
0.4	112
0.6	168
0.8	223
1	279
1.2	335
1.4	391
1.6	447
1.8	503
2	558
4	1117
6	1675
8	2233
10	2792

Microsoft Excel - nue

NUE for loblolly pine

Month	N	P	K	Ca	Mg
0.2	3	16	5	7	10
0.4	7	33	11	15	20
0.6	10	49	16	22	30
0.8	14	66	21	30	41
1	17	82	27	37	51
1.2	21	99	32	44	61
1.4	24	115	37	52	71
1.6	28	132	43	59	81
1.8	31	148	48	67	91
2	34	164	53	74	101
4	69	329	107	148	203
6	103	493	160	222	304
8	138	658	214	296	405
10	172	822	267	370	507
12	192	867	285	393	553
14	212	913	302	416	599
16	232	958	319	439	645
18	252	1003	337	461	692
20	272	1048	354	484	738
22	293	1094	371	507	784
24	313	1139	389	530	830

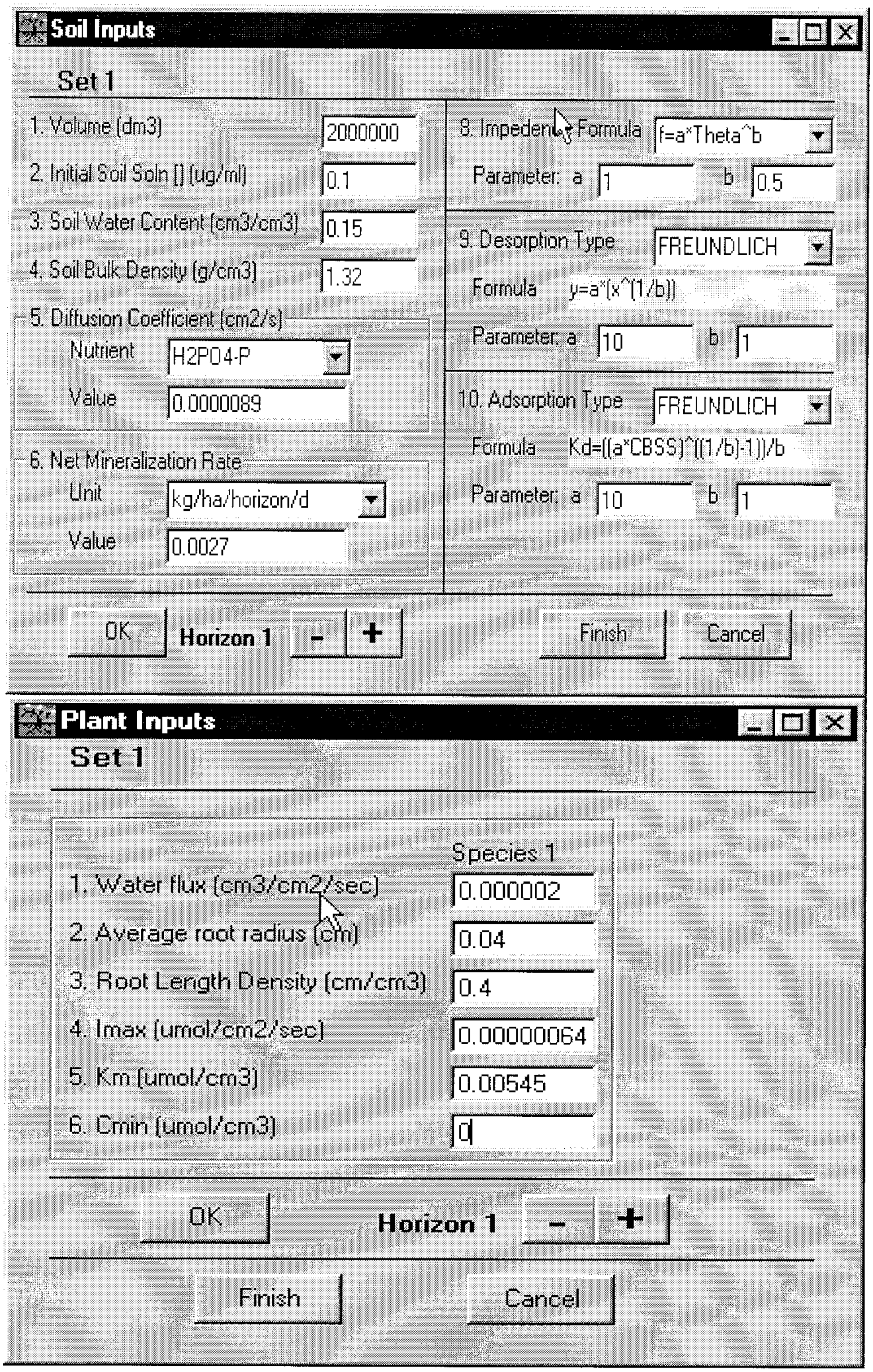
Figure 2—Biomass (a) and nutrient use efficiency (b) input files for the SSAND model

separated into sub-components for biomass and nutrient analysis. Fine root biomass, radius, and length were measured on 240 soil samples collected from 39 soil pits.

The development of the SSAND model is still in progress. After the model has been tested and validated for loblolly pine on Spodosols, the goal will be to evaluate its application to other soil types and forest tree species.

ACKNOWLEDGMENTS

We are thankful to the U.S. Department Of Energy who provided the funds for this study through Agenda 2020, the forest industry for its support and particularly to International Paper Company for providing sites and fieldwork logistics.



a

b

Figure 4—Parameters used in the SSAND nutrient uptake model: (a) soil inputs and (b) plant root and uptake kinetics inputs.

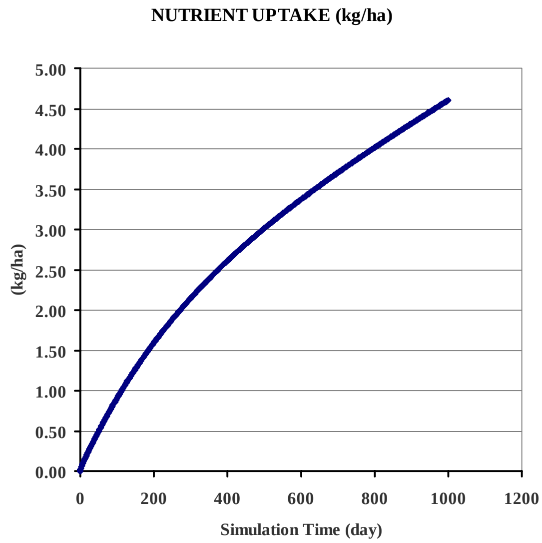


Figure 5—Simulated nutrient uptake over time for a hypothetical loblolly pine stand

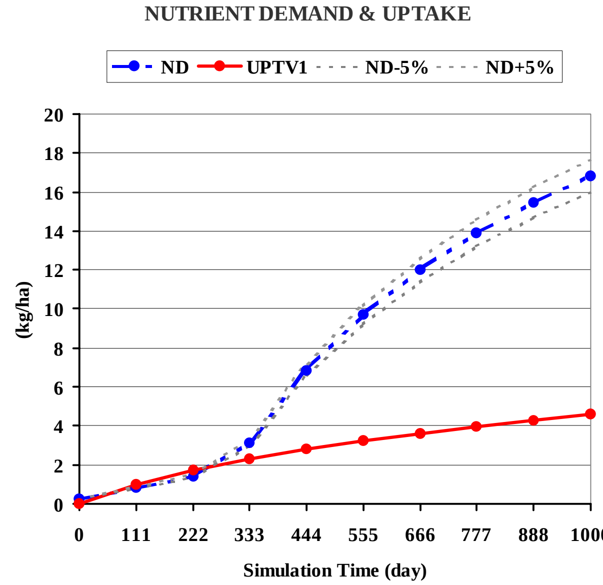
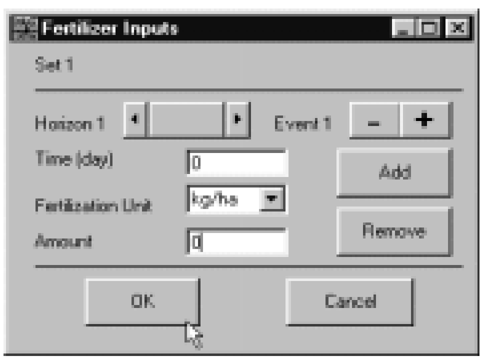
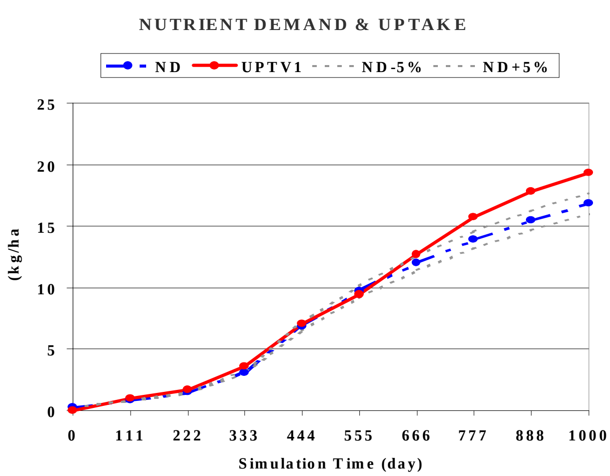


Figure 6—Comparison between required nutrient demand and simulated nutrient uptake. A nutrient limitation is shown to begin after 250 days. ND is nutrient demand and UPTV1 is simulated nutrient uptake.



a



b

Figure 7—Fertilizer input interface (a) and an evaluation of a fertilization regime designed to meet the nutrient demand of a stand growing at a predetermined production goald (b). ND is nutrient demand and UPTV1 is simulated nutrient uptake.

REFERENCES

Colbert, S.R.; Jokela, E.J.; Neary, D.G. 1990. Effects of annual fertilization and sustained weed control on dry matter partitioning, leaf area, and growth efficiency of juvenile loblolly and slash pine. Forest Science. 36: 995-1014.

Farnum, P.; Timmis, R.; Kulp, J.L. 1983. Biotechnology of forest yield. Science. 219: 694-702.

Jokela, E.J.; Martin, T.A. 2000. Effects of ontogeny and soil nutrient supply on production, allocation, and leaf area efficiency in loblolly and slash pine stands. Canadian Journal of Forest Research. 30: 1511-1524.

Neary, D.G.; Jokela, E.J.; Comerford, N.B.; Colbert, S.R.; Cooksey, T.E. 1990b. Understanding competition for soil nutrients – the key to site productivity on southeastern Coastal Plain Spodosols. In: Gessel S.P., Lacate D.S., Weetman G.F., and Powers R.F., eds. Proceedings of the Seventh North American Forest Soils Conference; 1988 July 24-28; Vancouver, BC: Faculty of Forestry, University of British Columbia: 432-450.

Neary, D.G.; Rockwood, D.L.; Comerford, N.B.; Swindel, B.F.; Cooksey, T.E. 1990a. Importance of weed control, fertilization, irrigation, and genetics in slash and loblolly pine early growth on poorly drained Spodosols. Forest Ecology and Management. 30: 271-281.

Prichett, W.L.; Comerford, N.B. 1982. Long-term response to phosphorus fertilization on selected southeastern Coastal Plain soils. Soil Science Society of America Journal. 46: 640-644.

Wood, C.W.; Mitchell, R.J.; Zutter, B.R.; Lin, C.L. 1992. Loblolly pine plant community effects on soil carbon and nitrogen. Soil Science. 154: 410-419.

GROWTH RESPONSE OF LOBLOLLY PINE TO INTERMEDIATE TREATMENT OF FIRE, HERBICIDE, AND FERTILIZER: PRELIMINARY RESULTS

L.M. Marino, B.P. Oswald, K.W. Farrish, H.M. Williams, and Daniel R. Unger[1]

Abstract—Crown area is an important factor in determining stem development. This study examined the changes in stem diameter per unit area of crown due to treatment with fire, herbicide, fertilizer, and tree-thinning practice. The experimental sites were mid-rotation loblolly pine (*Pinus taeda*) plantations that were thinned one year before treatment. Site 1 was strictly row-thinned and Site 2 was thinned by and within each row. Five replicates were installed on each site. Each replicate consisted of 8 subplots (0.1 ha) containing a central 0.04 ha measurement plot. A randomized-block split-plot design was used at each site, with fertilizer as the whole-plot factor and vegetation control treatment as the subplot factor. The herbicide treatment (approximately 4.5 L ha^{-1} Chopper®, 2.5 L ha^{-1} Accord®, 11.2 L ha^{-1} Sun-It II oil, and 76.7 L ha^{-1} water) was applied in October, 1999. Prescribed burning was performed in March, 2000, and fertilizer (224 kg ha^{-1} N and 28 kg ha^{-1} P) was applied in April following the burn. The height and diameter of each tree was measured at plot establishment (1999) and in December, 2000. Individual tree crown area was measured in June, 2000. A leaves-to-tree (LT) metric, defined as the ratio of a tree's diameter (cm) in December, 2000 to crown area (m^2) in June, 2000 was used to examine the impact of the various factors. Herbicide affected growth differently at the two sites; growth was increased at Site 1, but decreased at Site 2, relative to their respective controls. The results were unaffected by the use of fertilizer. Fire had a negligible effect on growth at both sites, with and without fertilizer. Herbicide and fire were additive at Site 2 but antagonistic at Site 1. The results suggest that thinning practices can significantly alter the impact of herbicides and fire on tree growth. Data from the second (and final) year of the study will be available in December, 2001.

INTRODUCTION

Crown dimension measurements are commonly used to study habitat for wildlife, encroachment rates into tree gaps, and many other aspects of tree growth (Fajvan and Grushecky 1996, Vales and Bunnell 1988, Zeide and Gresham 1991). Larger crown area often translates into more photosynthetic surface area, which can increase stem development. Many factors can affect crown size, including silvicultural treatments, thinning (Smith and others 1997), chemical control of woody competitors (Ezell and others 1997), prescribed fire (Wade and Johansen, 1986), and fertilization (Williams and Farrish 1994).

Crown growth represents the biological basis for the desired outcomes of increased tree growth and optimal use of limited space. However, few studies have systematically examined the impacts of fire, herbicide, fertilizer, and thinning practice on individual tree growth. This is a preliminary report of such a study in mid-rotational loblolly pine in East Texas.

METHODS

Study Sites

The study area consisted of two sites on land owned by International Paper Company in northeastern Texas. Both sites were thinned in 1998, 1 year before plot establishment. Site 1 was hand-planted on 1.8 m by 3.1 m spacing, and row-thinned and thinned within the rows to a basal area of 13 m^2 per ha before plot establishment. Soils were of the Darco, Teneha, and Osier series; slopes ranged from 3-15 percent. The site index was 65 at base age 25 years.

Site 2 was machine-planted on 1.8 m by 3.7 m spacing, and row-thinned to a basal area of 22 m^2/ha one year before plot establishment. Soils were of the Ruston and Attoyac series, with slopes ranging from 3-15 percent. The site index was 71 at base age 25 years.

Five replicates at both sites were established in 1999. Each replicate consisted of 8 treatment subplots (40 plots per site)each 0.10 ha in size. A central 0.04 ha

[1]Ph.D Student, Associate Professors, Assistant Professor, Arthur Temple College of Forestry,Stephen F. Austin State University, Nacogdoches, TX, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

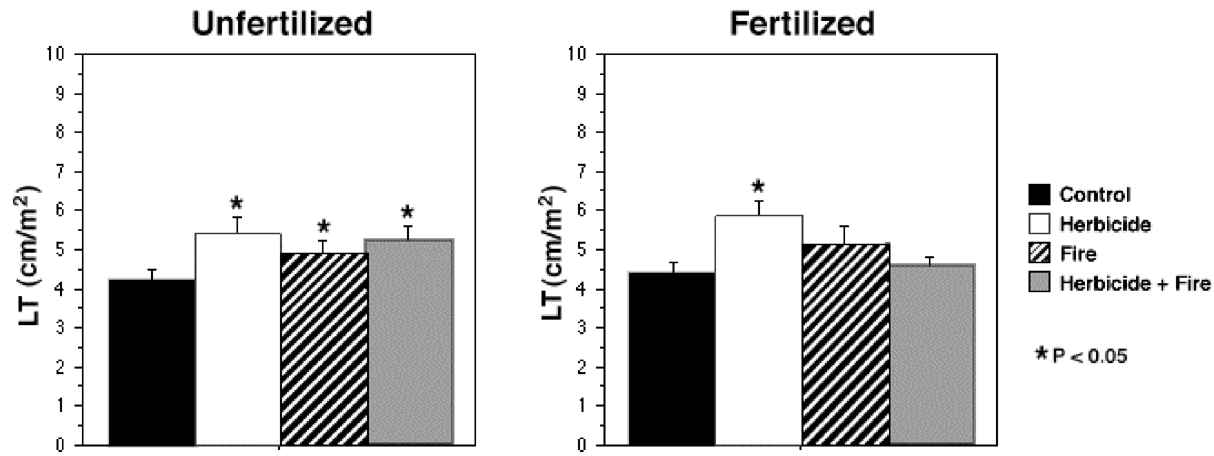


Figure 1—Effect of treatment on tree growth at Site 1, assessed using LT

measurement plot was established within each subplot. A randomized-block-split-plot design was used in which half of each replicate was randomly chosen for application of fertilizer, and each treatment (control, herbicide, prescribed fire, and herbicide/prescribed fire) was randomly assigned to the treatment subplots. A 10-m buffer separated each treatment subplot. All trees greater than 5 cm in diameter located within the subplots were tagged, identified to species, and measured for total height and DBH. There were approximately 20 and 35 trees per subplot at Sites 1 and 2, respectively.

Treatments

Due to a late summer drought, herbicide was applied in October, 1999. A herbicide mixture of 4.5 L/ha Chopper®, 2.2 L/ha Accord®, 11.2 L/ ha Sun-It® II oil, and 76.7 L /ha water was applied at Site 2. The same mixture was applied at Site 1, except that the amount of Accord® was increased to 2.5 L /ha, in an attempt to control a more dense understory. The mixtures were broadcast using a CO_2 backpack sprayer with a 3.66 m boom. Competing woody vegetation taller than 3.66 m was injected with a mixture of 100 ml Arsenal© AC diluted in 300 ml of water.

Firelines were installed around each burn plot to preserve the 10-m buffer. Prior to burning, ceramic tiles coated with strips of heat-sensitive paint (Tempilaq©) were installed at each plot center. The paint disintegrated at 100, 200, 400, 800, or 1000°C, thereby allowing for an estimate of fireline intensities. Four painted tiles per plot center were suspended from a rebar post at 4 levels: subsurface, surface, 0.3 m and 0.6 m aboveground.

The plots were prescribe-burned in March, 2000, using strip backfires. A backfire was used in an attempt to limit canopy damage due to scorch. Scorch heights (if any) were determined for each tagged tree.

In April following the burn, the fertilizer treatment was applied using a standard spreader. Diammonium

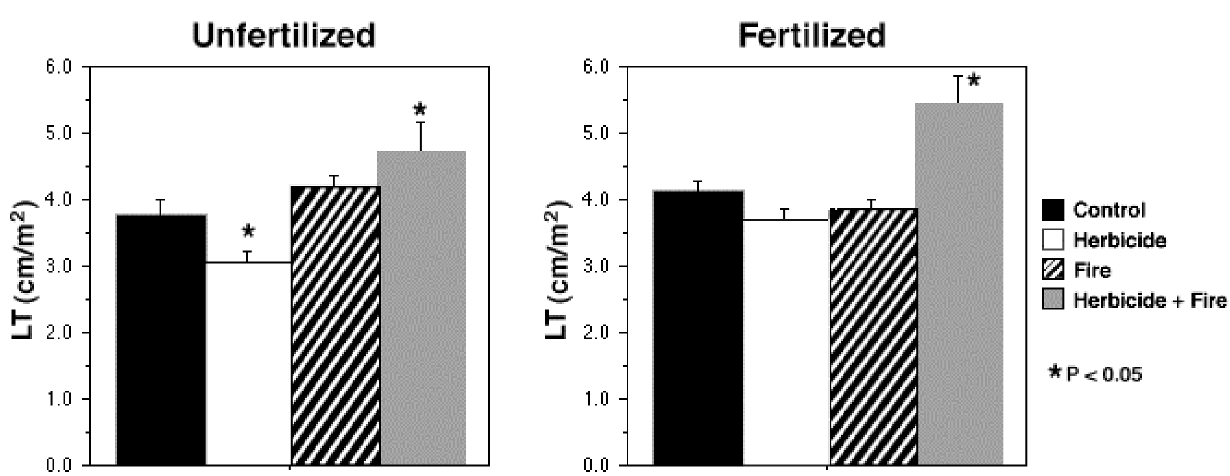


Figure 2—Effect of treatment on tree growth at Site 2, assessed using LT

phosphate (DAP) was and urea were applied at a rate of 224 kg/ ha N and 28 kg/ ha P, respectively.

Measurements

The crown area of each tree was determined in June, 2000 as follows (Farr and others 1989, Larocque and Marshall 1994, Peterson and others 1997). The length of the longest branch in each cardinal direction between the branch tip and tree stem was obtained using an electronic distance meter (Forestor Vertex, Haglof, Sweden). The area of the resulting polygon was calculated, after correcting for the radius of the tree. To ascertain the accuracy of the method, the results were compared with those calculated using 12 measurements per tree made at equal angular increments from a reference line. Use of 4 measurements consistently underestimated the crown area, but by less than 10 percent. The reproducibility of the measurement method was determined by making crown-area determinations on 10 different days, using 4 measurements per tree (5 trees). The average variation in the measurements was less than 7 percent.

The total height and outside bark DBH of each tagged tree were measured in December, 2000.

Study Metric and Statistical Analysis

To study the effect on tree growth of vegetative control (fire and herbicide), fertilizer, and thinning practice, it was necessary to control for any differences in tree diameter that existed prior to commencing the experiment. This was accomplished using a leaves-to-tree (LT) metric defined and calculated as follows. For each tree, the diameter (in cm) measured in December, 2000 was divided by the corresponding crown area (in m^2) measured in June, 2000. LT was, therefore, a simple measure of growth that related the diameter of the tree to its crown area measured 6 months earlier. The aim of the study was to determine how LT was affected by the study factors. For simplicity in interpretation, this was done on the basis of simple comparisons. Because LT was not normally distributed, differences were analyzed using the Mann-Whitney U test.

RESULTS AND DISCUSSION

At Site 1, herbicide treatment significantly increased growth, as assessed using LT (figure 1). The effect of fire was marginal, and it antagonized the effect of herbicide when the two treatments were combined (figure 1). Similar results occurred in both fertilized and unfertilized plots.

At Site 2, treatment with fire plus herbicide produced a significant increase in LT on both unfertilized and fertilized plots (figure 2). Either treatment alone had no beneficial effect.

Significant inter-site differences were seen in the response of the trees per unit of crown area to vegetative control. The differences could be due to the different thinning methods used at each site. Alternatively, they could be due to the slightly higher productivity at Site 1. the effect of thinning was likely more important because the addition of fertilizer had essentially no effect at either site.

There are at least two reasons that could explain why the prescribed fire was not as successful as herbicide treatment in promoting growth at Site 1. First, the dense understory was more easily controlled with the herbicide because the herbicides were selected specifically for control of the competing species actually present. In contrast, fire is known to affect some competing species more than others. Second, the relative humidity was 58 percent on the day the fire was applied. This could have reduced consumption of the competing vegetation. Analysis of post-burn fuel loading and temperature data may provide insight into the question.

Further Work

LT will be determined using stem diameters measured in December, 2001, thereby allowing assessment of the study hypotheses in the context of stem growth that occurred over a 2-year period. Stem maps and nearest-neighbor analysis will be used to examine individual tree growth response to treatment. Basal area growth and height growth will also be determined. This study is part of a larger study that is examining the physiological parameters, soil effects, and biodiversity changes in response to treatment.

Researchers will collaborate in order to fully characterize the response of mid-rotation loblolly pine to treatment with fire, herbicide, and fertilizer in East Texas.

ACKNOWLEDGMENTS

The authors thank the Forest Resources Institute, Arthur Temple College of Forestry, International Paper, Dr. Jimmie Yeiser, Dr. Dean Coble, and all graduate and undergraduate student involved with field measurements.

REFERENCES

Ezell, A. W.; Nelson, L. R.; Vollmer, J.; Minouque, P. J.; Catchot, A.L. 1997. Efficacy of dormant season basal applications of imazapyr and triclopyr for controlling undesirable woody stems. In: Waldrop, T. A., ed. Proceedings of the Ninth Biennial Southern Silvicultural Research Conference; 1997 February 25-27; Clemson SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U. S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 33-37.

Fajvan, M. A.; Grushecky S. T. 1996. Mapping Forest Architecture. Journal of Forestry. 94: 17-18.

Farr, W. A.; DeMars, D. J.; Dealy, J. E. 1989. Height and crown width related to diameter for open-grown western hemlock and Sitka spruce. Canadian Journal of Forest Research. 19: 1203-1207.

Laroque, G. R.; Marshall, P. L. 1994. Crown development in red pine stands. Canadian Journal of Forest Research. 24: 762-774.

Peterson, J. A.; Seiler, J. R.; Nowak, J.; Ginn, S. E.; Kreh, R. E. 1997. Growth and physiological responses of young loblolly pine stands to thinning. Forest Science. 43: 529-534.

Smith, W. R.; Farrar Jr., R. M.; Murphy, P. A.; Yeiser, J. L. 1992. Crown and basal area relationships of open-grown southern pines for modeling competition and growth. Canadian Journal of Forest Research. 22: 341-347.

Vales, D. J.; Bunnell, F. L. 1988. Comparison of methods for estimating forest overstory cover. I. Observer effects. Canadian Journal of Forest Research. 18: 606-609.

Wade, D. D.; Johansen, R. W. 1986. Effects of fire on southern herbicide application on growth and yield of older loblolly pine plantations- two year results. In: Edwards, M.B., comp. Proceedings of the Eighth biennial southern silvicultural research conference; 1994 November 1-3, Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 505-511.

Zeide, B., Greshham, C. A. 1991. Fractal dimensions of tree crowns in three loblolly pine plantations of coastal South Carolina. Canadian Journal of Forest Research. 21: 1208-1212.

EFFECTS OF MIDROTATION INTENSIVE SILVICULTURE ON FOREST SOILS IN EAST TEXAS: FIRST-YEAR RESULTS

S.A. Wilson, K.W. Farrish, B.P. Oswald, H.M. Williams, and J. L. Yeiser[1]

Abstract—Intensive forest management is becoming increasingly common in east Texas. Included in intensive management are such practices as mid-rotation fertilization, prescribed fire, and herbicide application. There is insufficient information about the effects of these treatments on soil physical, chemical, and biological properties when applied at mid-rotation. The objectives of this research are to evaluate the effects of these treatments on soil physical properties including organic matter content and bulk density; chemical properties including soil nitrogen and phosphorus; and on populations of resident earthworms. Five replications were installed in each of two loblolly pine (*Pinus taeda* L.) plantations aged 15 and 17. Both were thinned in 1998. Accord SP and Chopper emulsion were ground applied in the fall of 1999. The prescribed burn treatment occurred the following spring. Fertilizer was applied one to two weeks after completion of the burn to supply 224 kilograms per hectare of N and 28 kilograms per hectare of P. First-year results are presented.

INTRODUCTION

Intensive forest management, which is considered essential for meeting future timber production goals (Vann and Brooks, 1983), is becoming increasingly common in east Texas. Included in intensive management are such practices as mid-rotation fertilization, prescribed fire, and herbicide application. For example, as of 1996, fertilizer was applied to more than 150,000 hectares of loblolly pine (*Pinus taeda* L.) plantations in the United States each year (Zhang and Allen, 1996).

Each of these silvicultural practices has a number of potential effects on forest soils and tree nutrition. Fire, especially, has been shown to alter soil nutrient status, pH, and organic matter content. Fertilization and herbicide may have both indirect and direct effects on soil properties. These treatments may also impact earthworm populations, which can have long-term effects on soil fertility and structure (Francis and Fraser 1998, Thornes 1980). However, there is little information on the effects of these treatments when applied at mid-rotation in southern pine silviculture.

This study examines the individual and combined effects of fertilization, herbicide application, and prescribed burning on soils under two recently thinned mid-rotation loblolly pine plantations in Cherokee County, Texas. Baseline soil physical and chemical parameters were measured and monitored after treatment. The effects of intensive silviculture on earthworm populations are largely unknown; and this study evaluated effects of treatment on resident populations of earthworms.

MATERIALS AND METHODS

Study Sites

This study is located on two plantations in Cherokee County, Texas. The first site, referred to as the Cherokee Ridge site (CR), is on 78 hectares owned by the International Paper Corporation. The trees were planted in 1985, and were thinned to a basal area (BA) of 13.1 square meters in 1998. Soils on this site have sandy surface horizons, and include the Darco (Grossarenic Paleudult), Teneha (Arenic Hapludult), and Osier (Typic Psammaquent) series. The second site, referred to as the Sweet Union site (SU), is located on 45 hectares of land that is also owned by the International Paper Corporation. The trees were planted in 1982, and were row-thinned to a BA of approximately 22.0 square meters in 1998. The soils on this site have sandy loam surface horizons, and include the Ruston (Typic Paleudalf) and Attoyac (Typic Paleudult) series.

Experimental Design and Treatment Application

The experimental design is a split-plot, with fertilization as the whole plot treatment and competition control (herbicide, prescribed burning, both, or neither) as the sub-plot treatment. Five replications consisting of two 32 meter by 158 meter whole plots were installed at each site. Nested within each whole plot are four subplots measuring 32 meters by 32 meters (0.10 hectare), which are separated by 10 meter buffer strips. Within each sub-plot is an 11 meter radius (0.04 hectare) measurement plot.

Treatment application began in October of 1999. A mixture of 4.5 liters Chopper (imazapyr), 2.2 liters Accord SP (glyphosate), 11.2 liters Sun-It 2 oil, and 76.7 liters of water per hectare was applied at the Cherokee Ridge site using

[1]Research Assistant, Associate Professor, Associate Professor, Associate Professor, and T. L. L. Temple Chair, Arthur Temple College of Forestry, Stephen F. Austin State University, P.O. Box 6109 SFA Station, Nacogdoches, TX 75962-6109, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

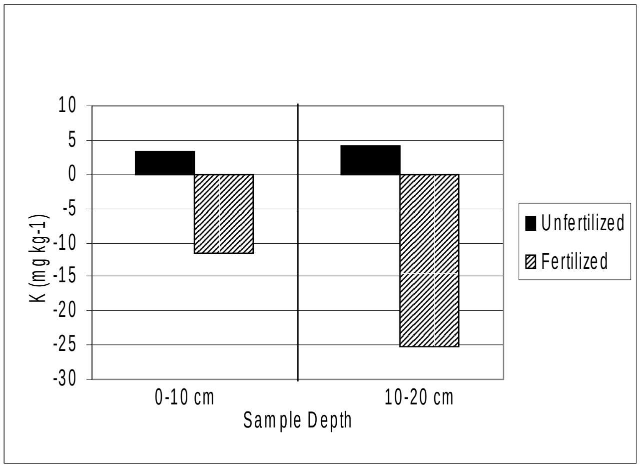


Figure 1-Change in K levels at the Cherokee Ridge site. In the fertilized plots, the level of K was greatly reduced by fertilization with urea and diammonium phosphate (DAP).

a backpack aerial sprayer with a 3.7 meter boom. At the Sweet Union site, a mixture of 4.5 liters Chopper, 2.5 liters Accord SP, 11.2 liters Sun-It 2 oil, and 76.7 liters of water per hectare was applied using the same backpack sprayer. Trees greater than 3.7 meters in height were injected with 100 milliliters of Arsenal AC (imazapyr) via the "hack and squirt" method; this is included in the total amount of imazapyr applied per plot. The prescribed burn treatment was applied in March of 2000, with fires applied as backfires to reduce damage from scorch. Tiles painted with heat-sensitive paints were installed in the center of each measurement plot to estimate temperatures at four levels: below the surface, ground level, 0.33 meter, and 0.66 meter. Fertilizers were applied in April of 2000, using diammonium phosphate and urea to supply 224 kilograms per hectare of nitrogen (N) and 28 kilograms per hectare of phosphorus (P).

Sampling Procedures

Soil samples were taken in July of 1999 and July of 2000 using an impact sampler and a bucket auger. Soil was sampled in three depth increments (0-10 centimeters, 10-20 centimeters, and the top 10 centimeters of the first B horizon), which were analyzed separately. The Soil, Plant, and Water Analysis Laboratory of Stephen F. Austin State University measured all micro- and macronutrients with the exception of N and P via the Ammonium Acetate EDTA method. P was measured using the Bray I method, and total N was determined via a LECO C/N Analyzer by the same lab. Earthworms were hand-sorted from a 0.25 meter sub-plot randomly located within each measurement plot. They were counted in the field, then were taken to the lab, re-counted, then oven-dried for biomass determination

RESULTS AND DISCUSSION

Cherokee Ridge

Competition control had no significant impact upon measured soil properties during the first year following treatment at this site. Soil pH was not affected by any of the treatments, nor was soil bulk density (Db). Organic matter content, measured as percent carbon, was also unaffected. Earthworm populations decreased at this site, from 376,000 per hectare in 1999 to 145,000 per hectare in 2000, a decrease of 61.4 percent. However, the population decrease was not correlated to forest management practices.

Total N was not affected by fertilization, but displayed a trend towards increasing in fertilized plots. Bray I-P remained constant regardless of fertilization. However, K dropped significantly (alpha = 0.05) as a result of fertilization in the top two samples (figure 1). The decrease

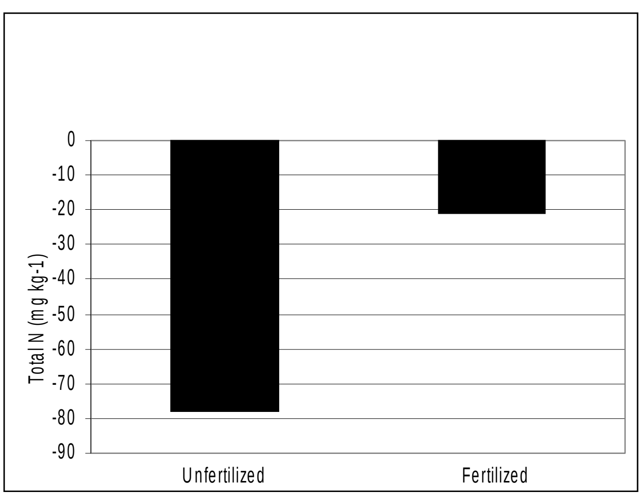


Figure 2-Change in total N at the Sweet Union site. Total N decreased in both fertilized and unfertilized plots, but decreased significantly less in the fertilized plots.

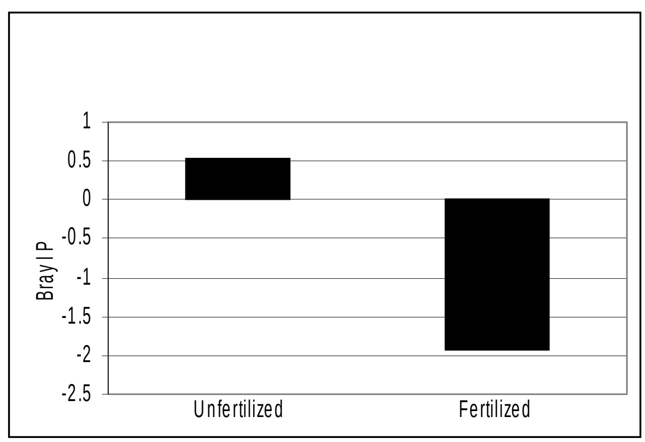


Figure 3-Change in Bray-I P at the Sweet Union site. Bray-I P increased in the unfertilized plots, and decreased in the fertilized plots, most likely due to uptake.

in K was most likely caused by leaching and was exacerbated by the sandy texture of the soils on this site.

Sweet Union

Soil bulk density and organic matter were unaffected by treatment at this site. Competition control had no significant effects on soil nutrient levels at this site. Earthworm populations decreased at this site as well, from 980,000 per hectare in 1999 to 734,000 in 2000, a decrease of 25.1 percent. This decrease was not correlated to management practices.

At this site, total N was unaffected by fertilization in the top 20 centimeters, but displayed a trend towards a decrease in fertilized plots. At the top of the B horizon, however, total N decreased significantly in both fertilized and unfertilized plots, but decreased less in plots receiving fertilization (figure 2).

Bray I-P was unaffected in the top 10 centimeters. In the 10-20 centimeter depth, P increased slightly in the unfertilized plots and decreased in the fertilized plots (figure 3). This is probably an uptake response.

At this site, magnesium was the only micronutrient that was significantly affected by fertilization; levels of Mg dropped in the 0-10 centimeter and B horizon depths. Leaching resulting from the influx of ammonium cations from fertilization probably caused this decrease. Soil pH also decreased in the 10-20 centimeter depth as a result of fertilization.

Both Sites

Of all of the treatments applied, fertilization was the only one to have significant impacts on the soils at these sites. Although fire can often have a number of effects on soils, the fires at these sites were relatively cool, which has minimized the fire impacts at these sites. The herbicides used in this study did not appear to have any effects on the soil properties that were measured.

The drought that the east Texas region has experienced for the last several years has almost certainly affected the outcomes of this project, especially the earthworm study. Although none of the treatments had statistically significant effects on earthworms, several trends became apparent during the course of sampling. Earthworm populations tended to be somewhat higher in plots that received herbicide and prescribed fire, either alone or combined, than in the control plots. Fire, especially, appeared to be beneficial; James (1988) found similar results in tallgrass prairie ecosystems. Furthermore, earthworm populations tended to be lower in plots that received fertilization than in the control plots. The number of sample plots for earthworms will be increased for the second sampling period of this study in the summer of 2001.

REFERENCES

Francis, G. S.; P. M. Fraser. 1998. The effects of three earthworm species on soil macroporosity and hydraulic conductivity. Applications of Soil Ecology. 10: 11-19.

James, S. 1988. The postfire environment and earthworm populations in tallgrass prairie. Ecology 69(2): 476-483.

Thornes, J. B. 1980. Erosional processes of running water and their spatial and temporal controls: a theoretical viewpoint. In: Kirkby, M. J.; R.P.C. Morgan. Soil erosion. New York, NY: John Wiley and Sons. 312 p.

Vann, J. R.; G. N. Brooks 1983. Forest fertilization in the south: a status report. Forestry Report R8-FR2: U.S. Department of Agriculture, Forest Service, Southern Region. 10 p.

Zhang, S.; H. L. Allen. 1996. Foliar nutrient dynamics of 11-year –old loblolly pine following nitrogen fertilization. Canadian Journal of Forest Research. 26: 1426-1439.

NITROGEN AND PHOSPHORUS USE EFFICIENCY IN STANDS OF LOBLOLLY AND SLASH PINE

Christopher A. Dicus and Thomas J. Dean[1]

Abstract—Nitrogen and phosphorus use efficiency (NUE and PUE, respectively), the annual amount of stemwood produced per unit net N or P used in total aboveground production, were examined in 17-year-old pure stands of unthinned loblolly pine (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Englem.) planted at two spacings. Slash pine stands had a greater NUE and PUE than loblolly pine, which was attributed to greater relative allocation of aboveground production to stemwood, lower foliar N and P concentrations, and greater foliar retranslocation of N and P by slash pine. Compared to 2.4 x 2.4 meter spaced stands, denser 1.2 x 1.2m spaced stands had lower NUE and PUE, which may be related to a sustained drought. Results of this study imply that nutrient management should differ in stands of varying composition and structure.

INTRODUCTION

In the southeastern United States, stand production of loblolly pine (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Engelm.) forests are often limited due to highly weathered soils that have low N and P base saturation. Potential production of southern pine plantations has been estimated to be twice that which is currently realized (Albaugh and others 1998, Sampson and Allen 1998). To increase production, nutrient management has become increasingly common. For example, 650,000 hectares of southern pine forests were fertilized in 1999, a 35 percent increase over the previous year[1]. While the effects of increased nutrient supply on forest production are readily recognized, there is a need to better understand the underlying mechanisms of nutrient dynamics so as to maximize returns on nutrient management investments.

N and P use efficiency (NUE and PUE, respectively), the amount of stemwood produced per unit N or P used in total aboveground production, is a quantitative measure of how effectively stands use these often-limiting nutrients to produce merchantable stemwood. Knowledge of how NUE and PUE vary could facilitate more sound nutrient management decisions. Any factor that influences stemwood production also likely affects NUE and PUE. For example, the inherently greater percentage of aboveground production allocated to stemwood by slash pine compared to loblolly pine (Colbert and others 1990) could potentially contribute to greater NUE and PUE by slash pine if nutrient uptake was equivalent between species. Likewise, any factor that influences the amount of N or P used to produce new aboveground biomass, such as differences in N or P concentration among the various biomass components or differences in the foliar retranslocation of these nutrients, could also affect NUE or PUE. This study investigated the effects of species and spacing on NUE and PUE in midrotation stands of loblolly and slash pine. Further, differences in biomass allocation, nutrient concentrations, and foliar retranslocation were examined as potential factors that influence NUE and PUE.

METHODS

Site

The study was conducted in a species and spacing trial planted in 1981 on the Lee Memorial Forest in southeast Louisiana. The predominant soil type within the study area is a fine-loamy, siliceous, thermic typic Paleudult (Ruston series). Loblolly or slash pine was planted in 25 x 25 meter plots at spacings of 1.2 x 1.2 meters and 2.4 x 2.4 meters. Each species and spacing combination was replicated 3 times in contiguous blocks.

Understory woody vegetation on each plot was cut with a chainsaw prior to data collection to minimize interspecific competition with overstory pine. Felled stems were left on-site and residual stumps were treated with the herbicide picloram. Measurements were restricted to an inner plot approximately 20 x 20 meters to minimize edge effects between treatment plots. Actual inner measurement plot boundaries varied by plot to include the total crown of all trees whose boles fell within a 20 x 20 meter area. All plot measurements were converted to a per hectare basis.

Nitrogen and Phosphorus Use Efficiency

Aboveground biomass production was estimated with regression equations. Each tree in each plot was numbered in 1996 and was measured for outside bark diameter at breast height (1.37 meters), total height and height to the base of the live crown after the 1996, 1997,

[1]Assistant Professor, Natural Resources Management Department, California Polytechnic State University, St. Luis Obispo, CA 93407; Associate Professor, School of Forestry, Wildlife, and fisheries, Louisiana State University Agricultural Center, Baton Rouge, LA 70803, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

and 1998 growing seasons. Using these measurements, standing first-year foliage, second-year foliage, stemwood, and branchwood mass for each loblolly pine tree were estimated with equations developed by Baldwin (1987) and Baldwin and others (1997). Slash pine biomass components were calculated with regression equations developed by Lohrey (1984). Lohrey (1984) did not distinguish between first-year and second-year foliage; therefore, to obtain an estimate of first-year foliage, the estimated total foliage on each slash pine tree was multiplied by 53.62 percent, the mean percentage of total loblolly pine foliage that consisted of first-year foliage.

Annual foliage production on each tree for a given year was the first-year foliage in the current year. Annual needle litter production for each year (used to calculate foliar retranslocation) was the second-year foliage in the current year. Annual stemwood and branchwood production on each tree were calculated by subtracting the previous-year standing biomass in each respective component from current-year standing biomass. Per-tree biomass production for each respective component was summed by plot and expanded to a per hectare basis. Two-year periodic mean annual production by component is the mean stand-level biomass production for each respective component averaged over 1997 and 1998.

To obtain N and P concentrations, first-year foliage, second-year foliage, and branchwood samples were collected in mid-September 1997 by shooting a midcanopy branch from 4 trees in each plot with a 12-gauge shotgun and #4 shot. Stemwood samples were obtained by coring four trees in each plot at breast height during December 1997. Needle litter samples were obtained in December 1997 by placing four 1 x 1 meter plastic sheets on the ground in each plot and collecting needle litter after 1 week.

Each component type was combined for each plot, oven-dried at 60°C for 48 hours, ground to pass a 40-mesh screen, and the resulting powder thoroughly mixed. N and P concentration were determined on 3 replicates of the mixture. N concentration was determined with the Dumas-method with a Leco FP-428 Analyzer. P concentration was determined with inductively coupled plasma (ICP) spectrometry (Huang and Schulte 1985). N and P concentration for each component in each plot was the mean of the 3 replicates.

Annual stand-level N and P in new biomass production for each component in each plot in each year was calculated by multiplying the periodic mean annual biomass production in each component in each plot by its corresponding nutrient concentration. A portion of N and P in new biomass production was assumed to have been supplied by foliar retranslocation. The total amount of retranslocated N and P was assumed to come partially from first-year foliage before its second year and partially from second-year foliage before senescence. Thus, the annual per-hectare N and P supplied by foliar retranslocation in each plot in each year was calculated as the difference in N content in first-year foliage from the previous year and N content in second-year foliage from the current year plus the difference in N content in second-year foliage in the previous year and N content in needle litter that fell in the previous year.

Net N and P used in total aboveground production were calculated as the difference between N or P in new aboveground biomass minus N or P that was supplied by foliar retranslocation. NUE and PUE were calculated as mean annual stemwood production (kg/ha per year) per unit net N or P used in total aboveground production (kg/ha per year).

Analysis

Species and initial spacing effects on individual variables were analyzed in a randomized complete block design by analysis of variance with a general linear model procedure (Statistical Analysis System Version 8, SAS Institute Inc., Cary, NC, USA). The general linear model included a variable for block, species (loblolly or slash pine), initial spacing (2.4 x 2.4 meters or 1.2 x 1.2 meters), and the interaction between species and initial spacing. The critical value for significant effects was set at 0.10.

RESULTS AND DISCUSSION

Slash pine had a greater NUE than loblolly pine, producing more stemwood per unit net N used in total aboveground production (figures 1a). There were no significant species by initial spacing interactions for any of the variables measured. Several factors contributed to greater NUE by slash pine. First, while absolute production of stemwood did not vary between species (P = 0.233), slash pine allocated a greater percentage of total aboveground production to stemwood than loblolly pine (67 percent and 63 percent, respectively; P = 0.072). This pattern is apparently manifested early in development as Colbert (1990) reported similar results for 4-year-old seedlings. A

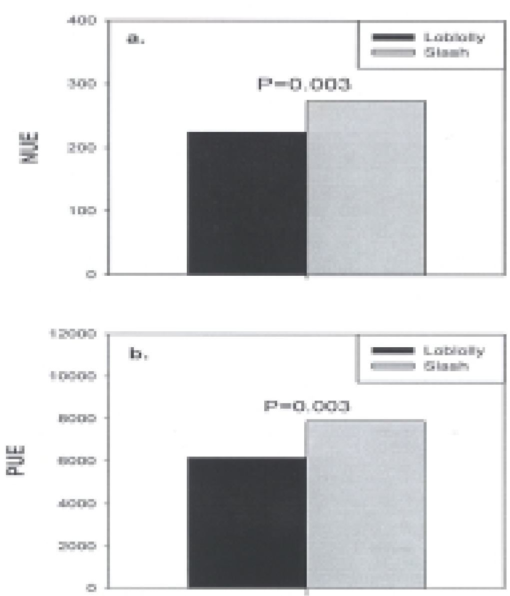


Figure 1—Nitrogen use efficiency (NUE) (a) and phosphorus use efficiency (PUE) (b) by species calculated as mean annual stemwood production (kg/ha per yr) per unit net N or P used in total aboveground production (kg/ha per yr). Data are from 17-year-old pure, unthinned stands of loblolly and slash pine in southeastern Louisiana.

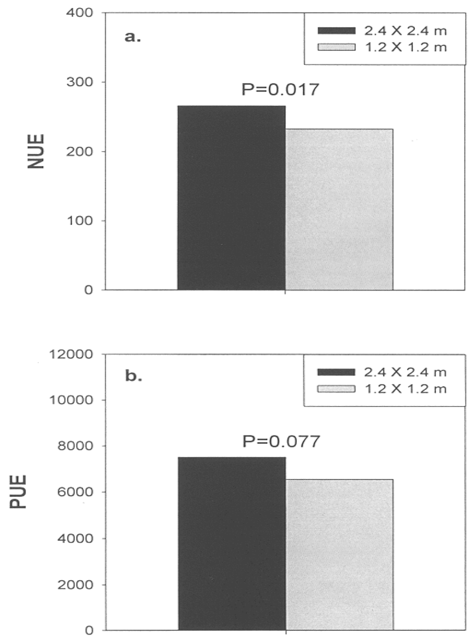


Figure 2—Nitrogen use efficiency (NUE) (a) and phosphorus use efficiency (PUE) (b) by initial spacing calculated as mean annual stemwood production (kg/ha per year) per unit net N or P used in total aboveground production (kg/ha per year). Data are from 17-year-old pure, unthinned stands of loblolly and slash pine in southeastern Louisiana.

lower N cost in new aboveground biomass also contributed to a greater NUE by slash pine as slash pine had lower N concentrations than loblolly pine in both first-year foliage (0.93 percent and 1.15 percent, respectively; P = 0.004) and branchwood (0.36 percent and 0.40 percent, respectively; P = 0.068). Further, slash pine foliage retranslocated a greater percentage of N during its lifespan than loblolly pine foliage (58.2 percent and 51.6 percent, respectively; P = 0.040).

Slash pine also had a greater PUE than loblolly pine (figure 1b). As with N, greater PUE by slash pine resulted in part from greater relative allocation to stemwood than loblolly pine. Again, slash pine had a lower P concentration in first-year foliage than loblolly pine (0.062 percent and 0.073 percent, respectively; P = 0.004). Although slash pine had greater P concentration in stemwood than loblolly pine (0.0045 percent and 0.0037 percent; P = 0.015), the relatively low concentration of stemwood did not appreciably affect total annual P demands. Slash pine foliage also had a greater percentage of P retranslocated during its lifetime than loblolly pine foliage (75.3 percent and 66.0 percent, respectively; P = 0.007).

Comparisons of initial spacing showed that NUE and PUE was greater in the 2.4 x 2.4 meter spaced stands than in the denser 1.2 x 1.2 meter spaced stands (figure 2), which was unexpected. Generally, foliar efficiency at producing stemwood increases with increasing stand density (Smith and Long 1989, Long and Smith 1990), and NUE and PUE were expected to follow a similar pattern. The decline in NUE and PUE in the denser 1.2 x 1.2 meter spaced stands may be related to a sustained drought that occurred during the study that likely caused intense intraspecific competition for water, particularly in the denser stands. As evidence for increased competition in the denser stands, 1.2 x 1.2 meters spaced stands had a significantly greater percentage of total volume lost each year to mortality than 2.4 x 2.4 meter spaced stands (1.32 percent and 0.08 percent per year, respectively; P = 0.001).

CONCLUSIONS

Slash pine stands had a greater NUE and PUE than loblolly pine, which was attributed to slash pine allocating a greater percentage of total aboveground production to stemwood, having lower foliar N and P concentrations, and retranslocating a greater percentage of N and P from foliage before senescence than loblolly pine. Both NUE and PUE declined with closer initial spacing, which was attributed to a drought that occurred during the study.

The results of this study illustrate how nutrient use efficiencies differ between stands of varying composition and structure. Thus, in light of the investment into intensive silviculture, it is apparent that forest managers must consider many variables in a sound nutrient management regime and a "one size fits all" approach is inappropriate.

ACKNOWLEDGMENTS

The Lucius Gilbert Foundation provided financial support. We are grateful for the assistance in field and lab work by a great number of people, particularly Jesús Franco and Erika Stelzer.

REFERENCES

Albaugh, T.J.; Allen, H.L.; Dougherty, P.M.; Kress, L.W.; King,J.S. 1998. Leaf area and above- and belowground growth responses of loblolly pine to nutrient and water additions. Forest Science. 44:1-12.

Baldwin, V.C., Jr. 1987. Green and dry-weight equations for above-ground components of planted loblolly pine trees in the West Gulf Region. Southern Journal of Applied Forestry. 11: 212-218.

Baldwin, V.C., Jr.; Peterson, K.D.; Burkhart, H.E.; Amateis, R.L.; Dougherty, P.M. 1997. Equations for estimating loblolly pine branch and foliage weight and surface area distributions. Canadian Journal of Forest Research. 27: 918-927.

Colbert, S.R.; Jokela, E.J.; Neary, D.G. 1990. Effects of annual fertilization and sustained week control on dry matter partitioning, leaf area, and growth efficiency of juvenile loblolly and slash pine. Forest Science. 36(4): 995-1014.

Huang, C-Y; Schulte, E.E. 1985. Digestion of plant tissue for analysis by ICP emission spectroscopy. Commun. Soil Sci. Plant Anal. 16: 943-958.

Lohrey, R.E. 1984. Aboveground biomass of planted and direct-seeded slash pine in the West Gulf Region. In: Saucier, J.R., ed. Proceedings of the 1984 Southern Forest Biomass Workshop, 1984 June 5-7; Athens, GA: 75-82.

Long, J.N.; Smith, F.W. 1990. Determinants of stemwood production in *Pinus contorta* var. *latifolia* forests: the influence of site quality and stand structure. Journal of Applied Ecology. 27: 847-856.

Sampson, D.A.; Allen, H.L. 1998. Light attenuation in a 14-year-old loblolly pine stand as influenced by fertilization and irrigation. Trees. 13: 80-87.

Smith, F.W.; Long, J.N. 1989. The influence of canopy architecture on stemwood production and growth efficiency of *Pinus contorta var. latifolia*. Journal of Applied Ecology. 26: 681-691.

Nurseries/Seed and Seedlings

Moderator:

DAVID SOUTH
Auburn University

IMPROVING LONGLEAF PINE SEEDLING PRODUCTION BY CONTROLLING SEED AND SEEDLING PATHOGENS

James P. Barnett and John M. McGilvray[1]

Abstract—The demand for container longleaf pine (*Pinus palustris* Mill.) planting stock is increasing across the Lower Gulf Coastal Plain. Poor-quality seeds and seedling losses during nursery culture further constrain a limited seed supply. Improved seed efficiency will be necessary to meet the need for increased seedling production. Seed presowing treatments and seedling fungicidal applications were evaluated in container longleaf pine seedling operations to determine if efficiency of seedling production could be improved. Application of treatments to reduce pathogenic fungi on seed and in seedling culture significantly increased plantable container stock.

INTRODUCTION

With a tenfold increase in seedling production occurring in the last few years, interest in the production and planting of longleaf pine (*Pinus palustris* Mill.) seedlings has reached an all time high. A limitation in producing even more seedlings is lack of high-quality seeds that not only germinate well, but result in plantable stock. Earlier results have shown that longleaf seed coats carry pathogenic fungi that not only reduce germination, but also result in significant seedling mortality (Barnett and others 1999). Pawuk (1978) and Fraedrich and Dwinell (1996) found that *Fusarium* spp. are commonly found on longleaf pine seeds and cause longleaf seedling mortality. Tests have shown that treating longleaf seeds with a sterilant or fungicide prior to sowing can improve both germination and seedling establishment (Barnett 1976, Barnett and Pesacreta 1993, Littke and others 1997). However, the effects of using both seed pretreatments to control seed-coat pathogens and fungicides to minimize seedling losses during the cultural period have not been reported. Our objectives were to develop recommendations for presowing treatments and fungicidal applications that will improve the efficiency of seedling production.

METHODS

The seeds used originated from bulked seed orchard lots of longleaf pine adapted to the Western Gulf Coastal Region. Seedlings were grown at the Southern Research Station's facility at Pineville, LA, following guidelines for producing longleaf pine container stock (Barnett and McGilvray 1997).

All seedlings were grown in Multipot 3-96ä containers, and both seed presowing treatments and seedling fungicidal applications were evaluated. The presowing treatments were a control and a hydrogen peroxide application—1-hour soak in 30-percent hydrogen peroxide (Barnett 1976, Barnett and McGilvray 1997). The seedling fungicide treatments included: (1) a control, and applications of (2) Benlate®, (3) Fungo-flo®, and (4) Fungo-flo® plus Subdue®. The fungicides were applied biweekly after seed germination was complete. The recommended concentrations of the fungicides used are: Benlate® 50WP (benomyl)—1 rounded teaspoon per gallon of water; Fungo-flo® (46.2 percent a.i. thiophanate-methyl)—0.2 fluid ounce per gallon of water; Fungo-flo® plus Subdue® 2E (metalaxyl) at 10 ppm active ingredient (0.15 ml per gallon of water).

The study was a randomized experiment with three replications of three trays each for each treatment replication. A total of 72 trays of 96 seedlings each was included in the study. The seeds were sown in late April 1999; seedling counts were made in December 1999 to determine the percentage of plantable seedlings (number of cavities with a plantable seedling divided by number of cavities with a germinant). Plantable seedling percentages differ from germination percentages in that losses of germinants due to disease are taken into consideration.

RESULTS

Both the seed and seedling treatments had a significant effect on plantable seedling percentages at the end of the study, and there were no statistical interactions between the presowing and fungicidal treatments (table 1). The hydrogen peroxide treatment of seed increased plantable seedlings from 85 to 93 percent; fungicide treatment of controls increased plantable seedlings from 78 to 92 percent. When the hydrogen peroxide seed treatment was used, 92 percent of the seedlings that did not receive fungicides were plantable. Fungicide applications to seedlings only improved average plantable stock by 2 percent.

Seedlings grown from seed that did not receive the hydrogen peroxide presowing treatment had a plantable seedling percentage of only 78, compared to 88 for those treated with fungicides during culture. There were no significant differences in the effectiveness of fungicides.

[1]Chief Silviculturist, Biological Technician, USDA Forest Service, Southern Research Station, Pineville, LA 71360, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Longleaf pine plantable seedling percentages resulting from seed and seedling treatments[a]

Seedling treatment	Seed treatment: Control	Seed treatment: Hydrogen peroxide	Average
	- - - - - - - *Percent* - - - - - - - -		
Control	78	92	85a
Benlate®	85	93	89b
Fungo-flo®	88	94	91b
Fungo-flo® plus Subdue®	90	94	92b
Average	85a	93b	

[a] Plantable seedling percentages (numbers plantable in November divided by numbers with an initial germinant) are averages for 288 seedling cavities for each of 3 replications. Averages within columns and across rows followed by the same letter are not significantly different at the 0.05 level.

DISCUSSION

Results from this study demonstrate the effectiveness of reducing fungal populations on longleaf pine seed coats before they are sown in containers. Elimination of pathogenic fungi from seed coats increases seedling establishment and reduces sources of disease infestation later in the nursery cultural period. Although 30-percent hydrogen peroxide was used in this study and is labelled as a stimulant of pine seed germination, earlier research has shown that a 10-minute Benlate® seed drench was equally effective and is a safer means of reducing seed coat pathogens (Barnett and others 1999). Benlate® has been labelled for conifer seed treatment in most of the southern States. Other fungicidal chemicals or methodologies also may be effective if they are not phytotoxic to seed germination.

There were no statistical differences among the fungicides used to reduce seedling losses during the nursery growing period. Because a great deal of research has demonstrated its effectiveness in controlling *Fusaria*, Benlate® was used as a kind of fungicidal standard. However, the label for this fungicide has been withdrawn for conifer nursery use. Fungo-flo®, a labelled replacement for Benlate®, is equally effective in controlling pathogens of longleaf seed and seedlings. Subdue® is normally added to the fungicidal application because it broadens the spectrum of disease protection to include other pathogens such as *Pythium* and *Rhizoctonia*.

Combing presowing seed treatments to reduce pathogenic fungi on the seed coats with the application of appropriate fungicides to seedlings during the growing season to control pathogenic fungi greatly increases the efficiency of container seedling production.

LITERATURE CITED

Barnett, J.P. 1976. Sterilizing southern pine seeds with hydrogen peroxide. Tree Planters' Notes. 27(3): 17-19, 24.

Barnett, J.P.; McGilvray, J.M. 1997. Practical guidelines for producing longleaf pine seedlings in containers. General Tech. Report SRS-14. Asheville, NC: USDA Forest Service, Southern Research Station. 28 p.

Barnett, J.P.; Pesacreta, T. C. 1993. Handling longleaf pine seeds for optimal nursery performance. Southern Journal of Applied Forestry. 17: 180-187.

Barnett, J.P.; Pickens, B.; Karrfalt, R. 1999. Longleaf pine seed presowing treatments: effects on germination and nursery establishment. In: Landis, T.D.; Barnett, J.P., tech. coords. National proceedings: forest and conservation nursery associations—1998. General Tech. Report SRS-25. Asheville, NC: USDA Forest Service, Southern Research Station: 43-46.

Fraedrich, S.W.; Dwinell, L.D. 1996. Mortality of longleaf pine seedlings caused by *Fusarium subglutinans* and an evaluation of potential inoculum services. In: Proceedings of the 3rd meeting of IUFRO Working Party 57.03.04; 1996 May 19-24; Orlando-Gainesville, FL: 48-54.

Littke, W.; Miller, H.; Milican, D. [and others]. 1997. The efficacy of Benlate seed-dip treatments to control seedborne *Fusarium* disease in containerized longleaf pine (*Pinus palustris*). Weyerhaeuser Research and Development Rep. 050-1422-97.1. Centralia, WA: Weyerhaeuser Forestry Laboratory. 22 p.

Pawuk, W.H. 1978. Damping-off of container-grown longleaf pine seedlings by seedborne *Fusaria*. Plant Disease Reporter. 62: 82-84.

RECALCITRANT BEHAVIOR OF TEMPERATE FOREST TREE SEEDS: STORAGE, BIOCHEMISTRY, AND PHYSIOLOGY

Kristina F. Connor and Sharon Sowa[1]

Abstract—The recalcitrant behavior of seeds of live oak (*Quercus virginiana* Mill.), and Durand oak (*Quercus durandii* Buckl.) was examined after hydrated storage at two temperatures, +4° C and -2° C for up to 1 year. Samples were collected and analyses performed at monthly intervals. At each sampling time, seeds were tested for viability and moisture content. Red buckeye (*Aesculus pavia* L.) seeds were similarly stored but analyzed at intervals of 3 months, while those of cherrybark oak (*Quercus pagoda* Raf.) and water oak (*Quercus nigra* L.) were tested yearly. Durand oak, live oak, and red buckeye seeds stored at -2° C maintained higher viability for a longer period of time than did those stored at +4° C. However, live oak acorns were damaged by the colder storage temperature. Sprouting during storage occurred at the higher storage temperature, but not at -2° C. After 2 years, water oak and cherrybark oak acorns which had been dried prior to refrigeration had lower viability than those stored fully hydrated. The damage was especially apparent in cherrybark acorns, with viability reduced after 1 year to 22 percent in those dried and then stored at -2° C and to 5 percent in those stored at +4° C. It is suggested that all precautions against desiccation be taken when collecting cherrybark and water oak acorns that are not for immediate use. Unless the acorns are collected when fresh and maintained in a fully hydrated state, severe losses can arise when stored for only 1 year. Fourier transform infrared spectrometry (FT-IR) studies have shown that cherrybark acorns subjected to severe desiccation exhibit irreversible changes in membrane lipid and protein secondary structure. This change was the most sensitive indicator of viability loss as yet encountered in these experiments. Future studies will examine the role of protein denaturation in seed deterioration.

INTRODUCTION

Early studies on low temperature storage of hardwood tree seeds resulted in the division of seeds into two storage behavior classes (Roberts 1973): 'Orthodox' seeds undergo a period of desiccation before being shed from the tree and can easily be stored at low temperatures for long periods of time at moisture contents of less than 12 percent. Temperate 'recalcitrant' seeds, however, do not undergo this final maturation drying and are thus very sensitive to moisture loss, making storage for any useful period extremely difficult. Immediate causes of seed viability loss are attack by pathogens and premature germination. Recent work has modified both Roberts' initial definition of recalcitrance and our perspective of the nature of recalcitrance. Pammenter and others (1994) and Berjak and Pammenter (1997) recognized the damage caused by aberrant metabolic processes while seeds are in hydrated storage and as water is lost. Thus, while much progress has been made in understanding the nature of recalcitrance, the storage of some recalcitrant tree seeds over a long period remains an insurmountable problem. North American genera containing species with recalcitrant seeds are *Castanea* (Pritchard and Manger 1990), and some *Acer*, *Aesculus*, and *Quercus* (Bonner 1990).

Acorns of the red oaks and of *Quercus robur* have reportedly been stored at -1° C or -2° C for periods up to 5 years in Europe (Suszka and Tylkowski 1980, 1982). Experiments here have been less successful, suggesting a varying degree of dormancy between European and U.S. species. We are reporting the results from three studies: (1) a 1 year storage study of Durand oak (*Quercus durandii* Buckley), live oak (*Quercus virginiana* Mill.), and red buckeye (*Aesculus pavia* L.) at 2 temperatures; (2) second year results of a water oak (*Quercus nigra* L.) and cherrybark oak (*Quercus pagoda* Raf.) acorn storage experiment at 2 temperatures and 2 moisture contents; and (3) a Fourier transform infrared (FT-IR) spectroscopy study of desiccating cherrybark oak acorns.

METHODS

Durand oak and red buckeye seeds were collected locally in Oktibbeha County, MS. The water oak and cherrybark oak acorns were purchased from a local supplier, while the live oak acorns were collected in Washington County, MS. All seeds were cleaned by floatation, soaked overnight, and then stored at 4° C until the start of the experiment. Original moisture contents for each drying regime were determined by drying 2-4 samples of seeds at 105° C for 16-17 hours. In preparation for germination tests, acorns were cut in half horizontally. The seed coat was removed from the half

[1]Plant Physiologist, USDA Forest Service, Southern Research Station, Starkville, MS; Biochemist, Indiana University of Pennsylvania, Indiana, PA, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

containing the embryo, and the half with the cup scar was discarded. Buckeye seeds were germinated intact. Germinations were conducted on moist Kimpak at an alternating temperature regime of 20° C for 16 h in the dark and 30° C for 8 h with light. Since sprouting in storage can be a common problem, counts were made at the start of each germination test of the number of seeds in a sample which had sprouted during storage. Experiments were conducted as follows:

Experiment 1

This experiment was conducted on tree species with highly recalcitrant seeds. Samples of 250 fully hydrated acorns of Durand oak and live oak were stored in plastic bags at either 4° C in a Lab-Line Ambi-Hi-Low Chamber or at -2° C in a modified chest freezer. Percent germinations and moisture content were determined for the fresh acorns and every 30 days thereafter for one year, as acorn supplies permitted. A subsample of acorns was dissected, and the embryos and cotyledons cryostored for future chemical and FT-IR spectroscopic analyses. Acorns were germinated as two replications of 50 seeds each per sampling period and were rehydrated overnight in tapwater prior to germination testing. Red buckeye seeds were stored as above; however, they were tested only at fresh, 90-, 180-, and 360-day intervals and were stored in batches of 59 seeds per bag. Germination tests consisted of 2 replications of 15 seeds each per sampling period.

Experiment 2

High and low moisture levels for water and cherrybark oak acorns were imposed by either soaking in tapwater for 16 hours or by drying on a lab bench for 48 hrs. Lots consisting of 110-120 acorns were stored in 4-mil polyethylene bags at either 4° C or at -2° C as described above. Original percent germinations and moisture contents were determined for fresh acorns and thereafter at yearly intervals. Acorns were germinated as two replications of 50 seeds per sampling period and were soaked overnight in tapwater prior to germination testing.

Experiment 3

Cherrybark oak acorns collected in 1999 were spread on blotter paper in a single layer on the lab bench. Cotyldeon samples of fresh seeds and those that had been dried for 2, 4, 6, and 8 days were analyzed by FT-IR spectroscopy as follows: Thin slices of cotyledon tissue were placed between CaF_2 windows of a demountable transmission cell. For each spectrum, 512 scans at 2/cm resolution were collected on a Nicolet 20 DXB spectrometer using an MCT-A detector. Single beam spectra were ratioed against an open beam background to yield transmission spectra. Sampling continued until seed moisture content dropped below 15 percent, and samples were analyzed for changes in macromolecular structure that might occur during drying and during rehydration. The experiment was replicated on acorns collected in 2000.

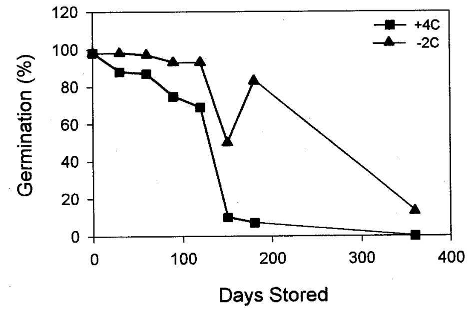


Figure 1—Viability of Durand oak (*Quercus durandii* Buckley) acorns stored for 1 year at 4° C and at -2° C.

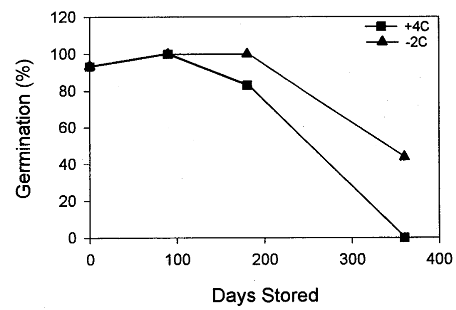


Figure 2—Viability of red buckeye (*Aesculus pavia* L.) seeds stored for 1 year at 4° C and at -2° C.

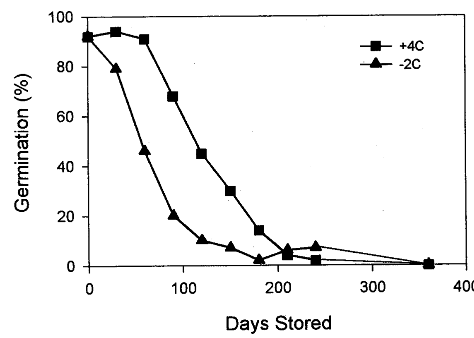


Figure 3—Viability of live oak (*Quercus virginiana* Mill.) acorns stored for 1 year at 4° C and at -2° C.

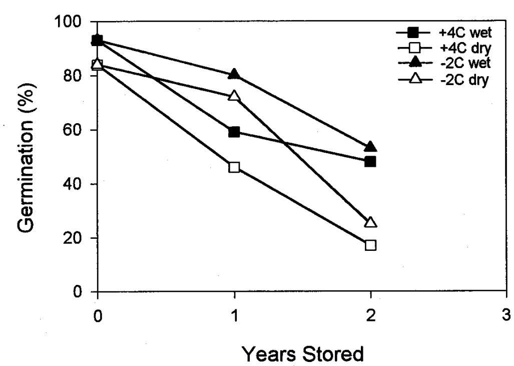


Figure 4—Water oak (*Quercus nigra* L.) acorns stored at two moisture contents and two temperatures.

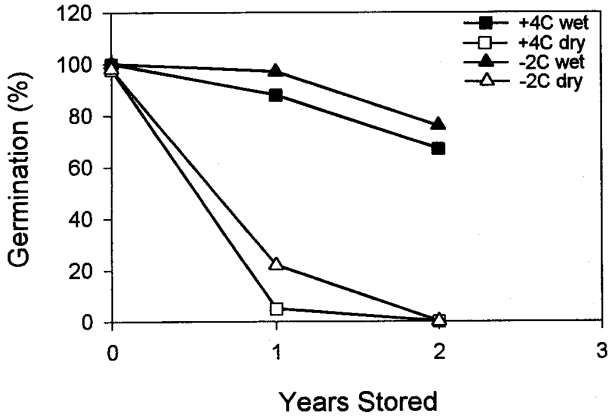


Figure 5—Cherrybark oak (*Quercus pagoda* Raf.) acorns stored at two moisture contents and two temperatures.

RESULTS

Experiment 1

Durand oak acorns stored at -2° C had significantly higher viability than those stored at 4° C in as little as 30 days (figure 1). After 210 days, acorns stored at -2° C averaged 83 percent viability, while only 6 percent of those stored at 4° C survived. Red buckeye seeds also remained viable longer if stored at -2° C (figure 2). The differences in viability did not occur, however, until after 90 days in storage. Acorns of live oak were the only ones tested to date that survive longer if stored at 4° C (figure 3). Storage at -2° C resulted in significant damage to the acorns. Fresh moisture contents were 38.1, 60.6, and 56.6 percent for Durand oak, red buckeye, and live oak, respectively, and did not change greatly during storage.

Experiment 2

Water oak acorn moisture content was 30.5 percent (on a fresh weight basis) for the fresh acorns and 25.6 percent for those dried 2 days prior to storage. Drying reduced initial acorn viability by 9 percent (figure 4). After 1 year, temperature of storage had a greater effect on seed viability than did initial moisture content. Both fully hydrated and dried acorns stored at -2° C maintained a higher viability than those stored at 4° C. This was not the case after 2 years of storage, when moisture content was the more important factor. Acorns which had been dried prior to refrigeration had lower viability than those stored fully hydrated. Moisture content did not change significantly throughout the course of the experiment.

Cherrybark oak acorn moisture content was 29.6 percent for the fresh acorns and 19.9 percent for those dried 2 days. However, drying reduced initial viability by only 2 percent (figure 5). Unlike water oak acorns, moisture content, and not temperature, was the important factor after both 1 and 2 years of storage. Only acorns stored in the fully hydrated condition retained high viability; dried acorns experienced significant losses in viability. after only 1 year in storage and were dead after 2 years. Changes in moisture content during storage were not significant.

Experiment 3

Cherrybark acorn germination was highly dependent on moisture content, and severely declined when seed moisture dropped below 17 percent (table 1). Changes in molecular structure due to drying and rehydration were measured by changes in the frequency (and bandwidth) of the infrared absorbance of lipid and protein functional groups. Membrane lipid structure was measured by the frequency and bandwidth of the symmetric CH_2 stretch at 2850/cm (Sowa and others 1991). An increase in vibrational frequency corresponds to increased fluidity (phase change from gel to liquid crystalline). In the liquid crystalline phase, membranes are fluid and in their normal state; when in the gel phase, membranes may leak cell solutes and cause irreparable damage to seeds. In this experiment, fresh tissues exhibited reversible shifts between gel and liquid crystalline phases upon drying and rehydration in the cotyledon tissue (figure 6). After drying for 8 days, membrane lipids changed to gel phase and did not recover their fluidity upon rehydration.

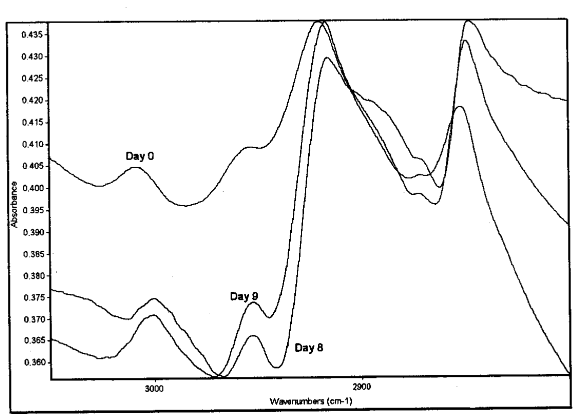


Figure 6—Membrane lipid vibrations in fresh (day 0) cherrybark acorn cotyledon tissue dried for 8 days, and then rehydrated (day 9). Peak frequencies are at 2850.9, 2847.2, and 2848.8 cm^{-1}.

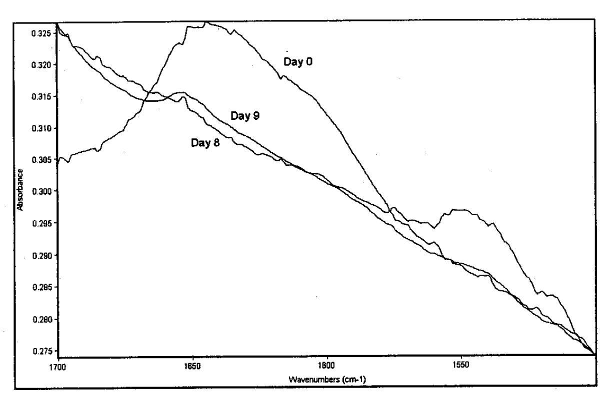


Figure 7—Amide protein vibrations in fresh (day 0) cherrybark acorn cotyledon tissue and in tissue dried for 8 days and then rehydrated (day 9).

Protein secondary structure was measured using the amide I and II vibrations near 1650 and 1550/cm (Sowa and others 1991). Changes in amide frequency correspond to changes in secondary structure. Alpha-helix structures absorb at higher frequencies, while beta-sheets absorb near 1630/cm; denatured protein typically exhibits extended beta-sheet conformation, with infrared absorbances common at frequencies less than 1630/cm. Irreversible changes in the protein secondary structure, illustrated by shifts in the amide absorbance near 1650/cm, occurred in the cherrybark acorn cotyledon tissue (figure 7). Secondary structure was completely lost upon dehydration (day 8) and remained so upon rehydration of these samples (day 9).

DISCUSSION

No one single temperature was best for storage of recalcitrant seeds. In previous experiments, chinkapin (*Quercus muehlenbergii* Engelm.), northern red (*Quercus rubra* L.), and Shumard (*Quercus shumardii* Buckl.) oak acorns favored the lower storage temperature of -2^{o} C (Connor and Bonner 1999). While Durand oak acorns and red buckeye seeds exhibited significantly higher viability when stored at -2^{o} C, live oak acorns were harmed by the low temperature. Also, sprouting during storage was a problem in red buckeye (17 percent after 180 days), live oak (18 percent after 120 days), and Durand oak seeds (16 percent after 120 days) stored at +4^{o} C. Sprouting remained below 2 percent in seeds stored at -2^{o} C for the same lengths of time.

Both water oak and cherrybark oak acorns retained high viability after 2 years when stored fully hydrated. To date, sprouting and changes in moisture content are not factors in the successful storage of either species. However, unlike a previous report (Connor and Bonner 1999), we did not find significant differences in viability caused by temperature of storage (figs. 4,5). Also, while drying of water oak and cherrybark acorns for 2 days before storage did not affect original viability, the damage was significant in water oak acorns stored for 1 year at +4^{o} C and in cherrybark oak acorns after 1 year at either storage temperature. It is therefore strongly suggested that all precautions against moisture loss be taken when collecting acorns of these species that are not for immediate use. Unless the acorns are collected when fresh and maintained in a fully hydrated state, severe losses can arise when stored for only 1 year. Orchard managers and seed processors must place emphasis on careful handling of acorns during the collection process. Also, the sooner acorns can be collected after dropping from the tree, and placed under refrigeration, the higher the probability of successful long-term (1 year) storage.

Membrane lipids changed phase from liquid crystalline to gel upon drying and did not recover upon rehydration as viability was lost. Ions can pass indiscriminately through cell membranes in the gel phase, and this loss of selective permeability ultimately results in seed mortality. In this experiment, the change occurred first in the cotyledon tissue and then in the embryos; since embryos in recalcitrant seeds maintain a fairly high water content (Connor and others 1996, 2001), this was not unexpected. It was interesting to note that after severe desiccation, rehydration did not restore membranes to their original fluid state.

Changes in protein secondary structure occurred in cotyledons as moisture was lost. Secondary structure was completely lost upon dehydration and remained so upon rehydration of nonviable samples. This evidence of protein denaturation occurring in the cytosol and/or cellular membranes was the most sensitive indicator of viability loss as yet encountered in these experiments. It is also contrary to behavior observed in orthodox seeds using infrared techniques (Golovina and others 1997) and will be addressed in future investigations.

LITERATURE CITED

Berjak, P.; Pammenter, N.W. 1997. Progress in the understanding and manipulation of desiccation-sensitive (recalcitrant) seeds. In: Ellis, R.H., Black, M., Murdoch, A.J., Hong, T.D. eds. Basic and applied aspects of seed biology: Proceedings of the Fifth International Workshop on Seeds; 1995 September 10-15. Reading, U.K.: Kluwer Academic Publishers: 689-703.

Bonner, F.T. 1990. Storage of seeds: potential and limitations for germplasm conservation. Forest Ecology and Management. 35: 35-43.

Connor, K.F.; Bonner, F.T. The effects of desiccation on seeds of *Acer saccharinum* and *Aesculus pavia*: recalcitrance in temperate tree seeds. Trees - Structure and Function.

Connor, K.F.; Bonner, F.T.; Vozzo, J.A. 1996. Effects of desiccation on temperate recalcitrant seeds: differential scanning calorimetry, gas chromatography, electron microscopy, and moisture studies on *Quercus nigra* and *Quercus alba*. Canadian Journal of Forest Research. 26: 1813-1821.

Golovina, E.A.; Wolkers, W.F.; Hoekstra, F.A. 1997. Behavior of membranes and proteins during natural seed aging. In: Ellis, R.H., Black, M., Murdoch, A.J., Hong, T.D. eds. Basic and applied aspects of seed biology: Proceedings of the Fifth International Workshop on Seeds; 1995 September 10-15. Reading, U.K.: Kluwer Academic Publishers: 787-796.

Pammenter, N.W.; Berjak, P.; Farrant, J.M.; Smith, M.T.; Ross, G. 1994. Why do stored hydrated recalcitrant seeds die? Seed Science Research. 4: 187-191.

Pritchard, H.W.; Manger, K.R. 1990. Quantal response of fruit and seed germination rate in *Quercus robur* L. and *Castanea sativa* Mill. to constant temperatures and photon dose. Journal of Experimental Botany. 41: 1549-1557.

Roberts, E.H. 1973. Predicting the storage life of seeds. Seed Science and Technology. 1: 499-514.

Sowa, S.; Connor, K.F.; Towill, L.E. 1991. Temperature changes in lipid and protein structure measured by Fourier Transform infrared spectrophotometry in intact pollen grains. Plant Science. 78: 1-9.

Suszka, B.; Tylkowski, T. 1980. Storage of acorns of the English oak (*Quercus robur* L.) over 1-5 winters. Arboretum Kornickie. 25: 199-229.

Suszka, B.; Tylkowski, T. 1982. Storage of acorns of the northern red oak (*Quercus borealis* Micz. = *Q. rubra* L.) over 1-5 winters. Arboretum Kornickie. 26: 253-306.

EFFECTS OF LIFTING METHOD, SEEDLING SIZE, AND HERBACEOUS WEED CONTROL ON FIRST-YEAR GROWTH OF LOBLOLLY PINE SEEDLINGS

Jason P. Reynolds, Thomas A. Greene, and John R. Britt[1]

Abstract—In fall, 1999, an experiment was installed to measure the effects and interactions of lifting method, seedling size, and weed competition on growth of loblolly pine (*P. teada*) seedlings during the first two growing seasons. Loblolly pine seedlings grown at two bed densities and lifted either by hand or machine were planted in southwestern Georgia and either given complete weed control or no weed control. The treatments were arranged in a 2 x 2 x 2 factorial and replicated three times. Mean root collar diameter was 5.7 mm for seedlings grown and 301/m^2 and 7.6 mm for seedlings grown at 161/ m^2. Total height of all seedlings was measured after planting and at the end of the 1st growing season. Ground line diameter was also measured at the end of the first growing season. This paper will present the main effects and their interaction on height and volume after the first growing season.

INTRODUCTION

There has been an increased interest from the forest industry throughout the South in large, high vigor seedlings. The industry's desire is to produce high quality pine seedlings, which not only survive planting, but begin growth during the first growing season. Seedling quality research has shown that variables such as root system size, stem caliper, and root/shoot ratio affect growth and survival of pine seedlings (South and others. 1995). The method of lifting seedlings from the nursery beds has also been shown to influence growth and survival (Greene & Danley,1999 , South & Stumpff, 1990). As part of a continuing series of seedling quality studies, an experiment was designed to look at the main effects and interactions of three factors that affect seedling performance. These factors are as follows:

1) Seedling size (large or small) controlled by seed bed density at the nursery;
2) The method of lifting (hand or machine); and
3) The presence or absence of herbaceous competition during the first growing season.

METHODS AND MATERIALS

This study was installed to look at the effects and interactions of the treatments throughout the first two growing seasons. The study design was a 2 X 2 X 2 factorial randomized complete block with three replications. The seedlings were planted in row plots at a 1.2-m x 3-m spacing. A total of 840 measurement trees were measured for the variables of interest.

The seedlings for this study were grown at two densities (301/m^2) and (161/m^2) at a nursery in Marion County, Georgia. The seedlings were lifted either by hand or by a two-row Mathis belt lifter, stored under refrigeration for two days and planted by researchers. The study was installed on a small field dominated by bermudagrass (*Cynodon dactylon)* and bahiagrass *(Paspalum notatum)*, which provided a high level of uniform competition throughout the growing season. The study plots either received total weed control throughout the growing season or no weed control. Planted heights and root collar diameters were measured at the time of planting. At the end of the first year, survival, height, and ground line diameter were measured.

In addition to the planted seedlings, 120 seedlings were destructively sampled for morphological characteristics; thirty trees from both densities and lift methods. Measurements taken from these seedlings included root collar diameter, dry shoot weight, and dry lateral and taproot weight.

RESULTS AND DISCUSSION

Seedling Sample Results

Seedling caliper was positively affected by lower seedbed density. Mean root collar diameter (RCD) was 5.7 mm for the seedlings grown at the higher seed bed density while the lower density seedlings had a mean diameter of 7.6 mm. The lifting method had a significant effect on lateral root weights where the hand lifted seedlings had greater dry weight than did the machine lifted seedlings. Total root weight was also affected by density where high-density seedlings had significantly less total root weight than did the low-density seedlings. Seedling diameters and weights by bed density and lifting method are presented in table 1. Significance levels for the treatment effects are presented in table 2.

[1]Reforestation Team, Mead Coated Board, Phenix City, AL 36867; Project Manager, The Nature Conservancy, Fort Benning, Columbus Georgia, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1— Dry weight means (grams) for the treatments from 120 seedlings sampled for morphology

Seedbed Density	Lifting method	Shoot weight (g)	Taproot weight (g)	Lateral root weight (g)	Total Root weight (g)	Shoot:Root ratio	RCD (mm)
Low	Hand	6.25	1.21	0.84	2.05	3.23	7.67
Low	Machine	5.71	1.21	0.74	1.94	2.98	7.61
High	Hand	3.45	0.57	0.72	1.29	2.74	5.61
High	Machine	3.25	0.57	0.47	1.04	3.38	5.71

Table 2— Significance levels for treatment terms in ANOVA models for the dry weights of the dependent variables from 120 seedlings sampled for morphology

Treatments	Shoot	Tap root	Lateral root	Total root	Shoot:Root	RCD
Significance	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr >F
Bed Density	0.000	0.000	0.009	0.000	0.726	0.000
Lift Method	0.25	0.979	0.014	0.143	0.185	0.798
Density X Lift	0.59	0.936	0.291	0.561	0.003	0.213

First Year Growth Effects

Seedbed Density—Although the lower seedbed density did produce larger seedlings, density was not a significant predictor of survival or height growth through the first year. This does not concur with previous experience or with published data (South and others 1995). Seedbed density was, however, a significant predictor of first-year volume and height. Further analysis was done using root collar diameter as a covariant to determine if there were any addition affects from seedbed density beyond seedling caliper differences. No additional variance was explained by bed density.

Lifting Method—Lifting method significantly improved first year survival and growth of seedlings. This affect can be explained by the greater retention of lateral root mass by the hand lifted seedling over that of the machine lifted seedlings. Table 1 shows that high density seedlings lifted by hand had nearly the same weight in lateral roots as did the machine lifted low density seedlings.

Herbaceous Weed Control—As expected, herbaceous weed control (HWC) significantly improved first year height growth, ground line diameter, survival, and volume index. The interaction of lifting method X HWC on volume index was significant at a 9 percent level of confidence. This interaction showed a greater positive response by hand lifted seedlings to weed control than those which were machine lifted, implying a more favorable response to silviculture from seedlings with more lateral root mass.

Significance levels for the treatments as they relate to the study plots are shown in table 3. First-year means for height and volume index are presented in figures 1 & 2 respectively. Table 4 presents the main effect means for the three randomized complete blocks. The means for all combinations of treatments are listed in table 5.

Table 3 – Significance levels for dependent variables for seedlings in three randomized complete blocks in South West, GA

Source of Variation	Percent survival	Volume index year 1 (cc)	Year 1 height growth (cm)	Year 1 height (cm)	GLD year 1 (mm)
Block	0.9911	0.8191	0.8211	0.9860	0.9851
Bed density	0.4091	0.0398	0.9231	0.0401	0.0068
Lift Method	0.0473	0.0254	0.0298	0.0162	0.0496
Weed Control	0.0473	0.0001	0.0003	0.0003	0.0001
Density X Lift Method	0.3159	0.4106	0.4652	0.3190	0.6555
Density X HWC	0.4091	0.9485	0.1564	0.1943	0.5189
Lift Method X HWC	0.4091	0.0974	0.1448	0.1293	0.2771
Density X Lift X HWC	0.7808	0.8004	0.8670	0.9221	0.9309

Table 4—Main effect means of survival, first flush length, height increment, and end-of-season height, ground line diameter, and volume index for seedlings planted in three randomized complete blocks in Southwest, Georgia in 2000

Level of Main effect	Survival (percent)	First flush length (cm)	Volume index year 1 (cc)	Height growth year 1 (cm)	Height year 1 (cm)	Ground line diameter year 1 (mm)
			DENSITY			
LOW	92 a	15 a	14 a	31 a	54 a	9.3 a
HIGH	95 a	13 b	11 b	31 a	49 b	8.3 b
			LIFTING			
HAND	97 a	15 a	14 a	34 a	54 a	9.4 a
MACHINE	89 b	13 b	11 b	29 b	49 b	8.4 b
			HWC			
YES	97 a	14 b	18 a	36 a	56 a	10.7 a
NO	89 b	15 a	7 b	26 b	47 b	6.9 b

A difference in letters indicates significant difference at p=0.05 from Duncan's multiple range test.

Table 5 – Year 1 means for all treatments from seedlings planted in Southwest, Georgia in 2000

Seedbed Density	Lift method	HWC	Survival (percent)	Height growth	Height	Diameter	Volume index
high	hand	no	93	25	43	6.3	5
high	hand	yes	100	41	59	10.7	19
high	machine	no	85	25	44	6.2	5
high	machine	yes	100	34	52	9.8	14
low	hand	no	96	30	53	7.7	9
low	hand	yes	99	40	62	11.7	24
low	machine	no	83	26	48	7.3	7
low	machine	yes	89	30	52	10.5	16

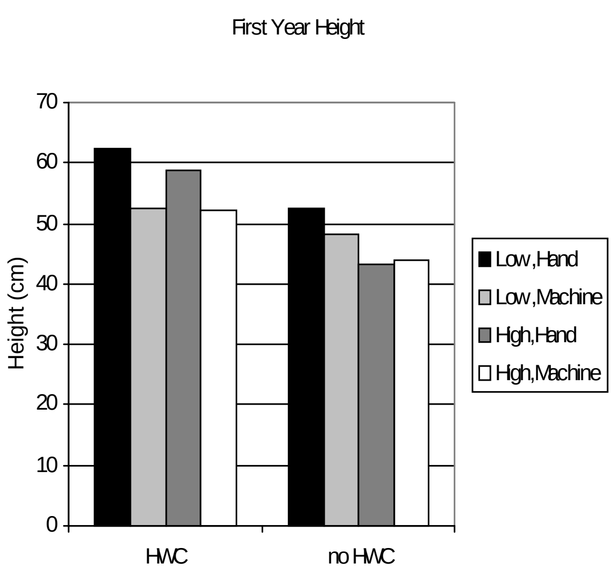


Figure 1— First year incremental height growth of the various treatments. Significant at p = 0.05 level on lifting method and weed control.

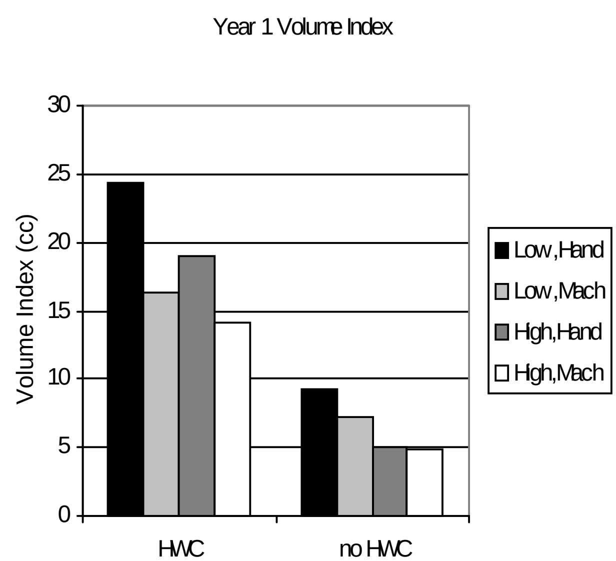


Figure 2—First year volume index of the various treatments. Significant at p = 0.05 for all treatments.

CONCLUSIONS

The results from this study indicate that seedling quality has a significant impact on first year performance of loblolly plantations. Larger seedlings have greater volume through the first year than do smaller seedlings. Hand lifting seedlings improves lateral root mass retention. As a result, hand lifted seedlings have greater first year growth and survival than machine lifted seedlings. Herbaceous weed control during the first year improves survival and growth of seedlings. Furthermore, there is some evidence to suggest that high quality, vigorous seedlings, respond more favorably to the silvicultural treatment of weed control.

Therefore, nursery practices that produce large caliper, vigorous seedlings, and lifting methods which limit damage to the seedling's stem and root system are encourage due to the seedling's superior performance in the field. In order to realize the full benefit of the investments of silvicultural treatments in a plantation, the use of high quality seedlings that are cared for properly should be considered a key tool to plantation success.

REFERENCES

Greene, T.A.; Danley T.S. 1999. Effect of lifting method on first-year growth of loblolly pine seedlings. In: Haywood, J.D., ed. Proceedings of the Tenth biennial southern silvicultural research conference; 1999 February 16-18, Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 334-338.

South, D.B.; Stumpff, N.J. 1990. Root stripping reduces root growth potential of loblolly pine seedlings. Southern Journal of Applied Forestry. 14: 196-199.

South, D.B.; Zwolinski, J.B.; Allen, H.L. 1995. Economic returns from enhancing loblolly pine establishment on two upland sites: effects of seedling grade, fertilization, hexazinone, and intensive soil cultivation. New Forests. 10: 239-256.

EFFECTS OF FLOOD DURATION AND DEPTH ON GERMINATION OF CHERRYBARK, POST, SOUTHERN RED, WHITE, AND WILLOW OAK ACORNS

Yanfei Guo, Michael G. Shelton, and Eric Heitzman[1]

Abstract—Effects of flood duration (0, 10, 20, and 30 days) and depth (10 and 100 centimeters below a water surface) on acorn germination were tested for two bottomland oaks (cherrybark oak [*Quercus pagoda* Raf.] and willow oak [*Q. phellos* L.]) and three upland oaks (post oak [*Q. stellata* Wang.], southern red oak [*Q. falcata* Michx.], and white oak [*Q. alba* L.]). The study was a 4 x 2 factorial with a completely randomized design. Acorns of the five species were collected in November 1995 in Drew County, Arkansas and stored in a refrigerator at 4 degrees Centigrade until stratification. Acorns were stratified for 45 days in plastic germination flats with 20-cubic centimeter cells filled with a silt loam soil and then flooded in a small pond from March 19 to April 18, 1996. After flooding, acorns were germinated for 60 days. Flood depth did not significantly affect germination of any species, but flood duration affected germination of the three upland species. There was no interaction between flood duration and depth for any species. Among the upland species, germination of white oak acorns with 20 days or more of flooding was almost totally prohibited, while germination of southern red oak acorns gradually decreased as flood duration increased. Although germination of post oak was significantly reduced by 20 and 30 days of flooding, more than 65 percent of the acorns germinated. Results of our study indicate that the effects of flooding on the species composition of bottomlands begin with the germination process.

INTRODUCTION

Seasonal flooding frequently occurs in bottomlands and is a principal factor in determining tree species distribution (Hodges and Switzer 1979). Flooding may affect tree growth by displacing soil air and limiting root respiration along with other effects, and extended flooding can kill flood-intolerant trees (Kramer and Kozlowski 1979). Flood tolerance of the major bottomland hardwood species, including many oaks, has been summarized (Hook 1984; Allen and Kennedy 1989), but little is known about the flood tolerance of tree seeds. For instance, some species can develop aerenchymatous tissue to facilitate transport of oxygen to the roots, but this is not possible for seeds (Norton 1986). For the oaks, acorns of some species may be damaged by extended flooding, and damaged acorns may not be able to germinate or produce vigorous seedlings. There is some indication that acorns of the bottomland oaks can tolerate more flooding than upland species. For instance, 15 days of flooding severely reduced acorn germination of white oak (*Quercus alba* L.) (Bell 1975), but acorns of Nuttall oak (*Q. nuttallii* Palmer) were not affected by 34 days of flooding (Briscoe 1961). Guo and others (1998) found that spring flooding significantly reduced epicotyl emergence of black (*Q. velutina* Lam.) and northern red oak (*Q. rubra* L.) acorns but did not affect cherrybark (*Q. pagoda* Raf.) or water oak (*Q. nigra* L.).

Water depth may vary greatly during flooding based on location within the floodplain and intensity of the flood. Water depth may affect aeration, temperature, and pressure, which may influence acorn viability. The effect of flood depth on acorn germination has not been studied. Therefore, the objective of this study was to test the effects of flood duration and depth on acorn germination of five oak species common to the southern United States. The species were two bottomland oaks (cherrybark and willow oak [*Q. phellos* L.]) and three upland oaks (post oak [*Q. stellata* Wang.], southern red oak [*Q. falcata* Michx.], and white oak).

METHODS

In November 1995, acorns from an individual tree of the five oak species were collected in Drew County, AR. After conducting a float test, acorns were air dried overnight and stored in polyethylene bags at 4 degrees Centigrade. A silt loam soil (Typic Ochraquults) was collected in Drew County, AR. The soil was air dried and hand-processed to pass a 5-millimeter sieve. Plastic germination flats with sixty 20-cubic centimeter cells per flat were filled with soil, and twelve acorns of each of the five species were buried 1 centimeter below the soil surface with one acorn per cell. Acorns were buried in soil because small mammals commonly bury acorns and survival of acorns on the forest floor is generally low (Bowersox 1993). After sowing, the soil was saturated with distilled water, and flats were

[1]Assistant Professor, Assistant Professor, School of Forest Resources, University of Arkansas-Monticello, Monticello, AR 71656; Research Forester, Southern Research Station, USDA Forest Service, Monticello, AR, 71656, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

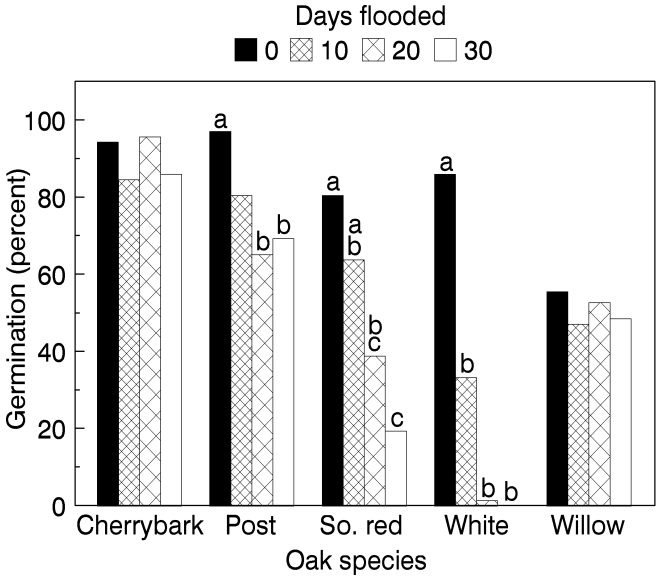


Figure 1—Effects of flood duration on germination of cherrybark, post, southern red, white, and willow oak acorns. Bars of a cluster with different letters differ at α =0.05.

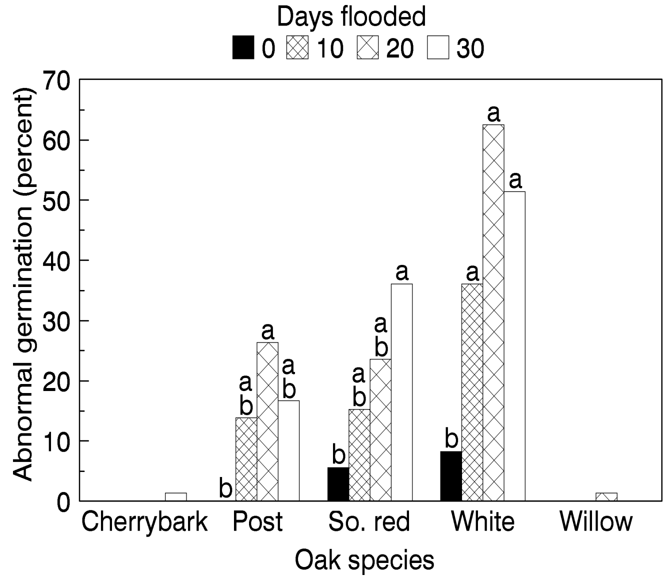


Figure 2—Effects of flood duration on the abnormal germination (a radicle or roots produced with no accompanying epicotyl or shoot) of cherrybark, post, southern red, white, and willow oak acorns. Bars of a cluster with different letters differ at α =0.05.

stored for 45 days at 4 degrees Centigrade to stratify acorns, assuring a uniform state of dormancy.

The study design was a 4 x 2 factorial with a completely randomized layout with treatments of flood duration and depth. There were four flood durations: 0 (control), 10, 20, and 30 days, and two flood depths: 10 and 100 centimeters below a water surface. Each treatment combination was replicated three times with 12 acorns per replicate. Flooding was conducted in a 0.2-ha pond in Drew County, AR from March 19 to April 18, 1996. Plastic germination flats with the 10-centimeter depth were protected with a wire screen (1.2-centimeter mesh) to keep out seed-consuming animals. A maximum-minimum thermometer was submerged with germination flats, and water temperature was recorded every 10 days. Flooding of replicates of the 10- and 20-day treatments was staggered in time so that environmental gradients occurring over the 30-day period could affect all treatment levels. Plastic germination flats awaiting flooding and those with completed flooding treatments were drained and stored at 4 degrees Centigrade until day 30 when all germination flats were collected. Minimum water temperatures for the 10-centimeter depth were 10.1, 11.0, and 14.6 degrees Centigrade, respectfully, for the three 10-day flooding periods, and maximum temperatures were 17.4, 19.3, and 22.3 degrees Centigrade. Corresponding minimum temperatures for the 100-centimeter depth were 10.6, 11.9, and 14.6 degrees Centigrade, and maximum temperatures were 14.4, 16.8, and 18.2 degrees Centigrade.

For germination tests, the plastic germination flats were placed in a laboratory with a bay of south-facing windows, exposing flats to diffuse sunlight. The germination flats were periodically irrigated with distilled water to keep the soil moist. Temperature in the laboratory was maintained at 20 degrees Centigrade. Epicotyl emergence of each acorn was recorded weekly over an 8-week period when length exceeded 2 centimeters. Seedlings were allowed to continue development in the germination flats after acorns were recorded as germinated. To assess possible germination activity at the time of flooding, subsamples of acorns were established that were identical to the unflooded control, except that they were removed from soil and examined at the beginning of the germination test; the four activity classes were none, acorn split, radicle ≤ 5 millimeters, and radicle >5 millimeters. At the end of the germination test, all ungerminated acorns were examined for decay and abnormal germination (a radicle or roots exceeding 2 centimeters but no corresponding shoot).

Germination results were analyzed by GLM of SAS (SAS Institute Inc. 1986). Significance was accepted at $\alpha = 0.05$. Means were separated by the Ryan-Einot-Gabriel-Welsch multiple range test at $\alpha = 0.05$.

RESULTS

Flood duration significantly affected germination of post ($P = 0.03$), southern red ($P < 0.01$), and white ($P < 0.01$) oak acorns, but did not affect cherrybark ($P = 0.12$) and willow ($P = 0.89$) oak acorns. Flood depth did not significantly affect germination of any species, and there was also no significant interaction between flood duration and depth. Temperatures averaged 15.8 degrees Centigrade for the 10-centimeter depth and 14.4 degrees Centigrade for the 100-centimeter depth, but the slight lowering of average temperature with increasing water depth was apparently not enough to affect flood damage.

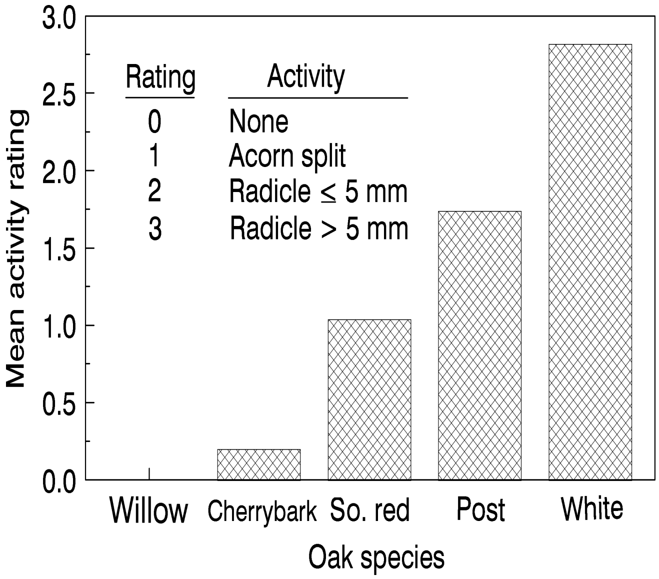


Figure 3—Activity rating of unflooded acorns of cherrybark, post, southern red, white, and willow oaks determined after 75 days of stratification which coincided with the end of the flooding treatments.

Germination rate of the control for post oak acorns was 97 percent, which did not differ from the 10-day flooding (81 percent) but was significantly greater than the 69 and 65 percent of the 20- and 30-day flooding treatments (figure 1). No difference was found among the three flood duration treatments. For southern red oak acorns, germination rate of the control was 81 percent. That was not different from the 10-day flood treatment at 64 percent but was significantly different from the 20- and 30-day treatments (39 and 19 percent). There were no differences between the 10- and 20-day treatments and between 20- and 30-day treatments. Compared to post and southern red oak, acorns of white oak were more severely affected by flooding. Germination rate of the control was 86 percent. With 10-day flooding, germination was reduced to 33 percent, which was significantly different from the control. Almost no germination occurred with the 20- and 30-day durations.

Cherrybark oak germination varied from 95 to 85 percent with the greatest germination rate occurring with 20-day flooding. Willow oak acorns varied within a narrow range (47-55 percent), but the germination rate was much lower than that of cherrybark oak.

Germination failures of post, southern red, and white oaks were mostly accounted for by abnormal germination, where radicles or roots developed without accompanying epicotyls or shoots (figure 2). Abnormal germination generally increased for these species with increasing flood duration. In contrast, abnormal germination was nearly nil for cherrybark and willow oak. For willow oak, most of the acorns that did not germinate were classified as being decayed, averaging 42 percent across all durations with no significant treatment effects.

The activity of unflooded acorns at the end of 75 days of stratification was considerably less for bottomland species than for upland species (figure 3). Willow and cherrybark oak acorns showed almost no activity. Most of the southern red oak acorns were split, but no radicles had emerged. In contrast, most post oak acorns had radicles less than 5 millimeters long, while most radicles of white oak were longer than 5 millimeters.

DISCUSSION

Among the five tested species, post, southern red, and white oaks are upland species, while cherrybark and willow oaks are bottomland species. However, cherrybark oak is seldom abundant on wet or swampy soils, and it grows best on loamy sites on the first bottom ridges (Krinard 1990). Willow oak is found on ridges and high flats of first bottoms of major streams, and on ridges, flats, and sloughs on second bottoms, but it grows best on clay loam ridges of new alluvium (Schlaegel 1990).

Cherrybark oak acorns are tolerant to flooding at least up to 30 days (Guo and others 1998). This study further shows that flooding in deep water in spring does not affect acorn germination of the species. Germination rates of the acorns were high, ranging from 81 to 97 percent across the treatments. In contrast, germination of willow oak acorns was only around 50 percent, including the control. It is not clear why the willow oak acorns had such low germination rates. Bonner (1974) found different germination rates for willow oak acorns collected at different dates; acorns collected on October 6 had a germination rate of 59 percent, compared to 86 percent on October 18, and 96 percent on November 1. Although our acorns were collected in November, they could have possibly fallen to the ground earlier.

For the three species affected by flooding, post oak showed considerable tolerance to flood damage. Even after 30 days of flooding, more than 65 percent of the post oak acorns germinated normally. Thus, flooding damage to acorns is probably not a significant factor limiting the distribution of post oak. Southern red oak also showed some tolerance to short-term flooding; the germination rate was more than 50 percent for 10 days of flooding. Thus, a short flooding period about 10 days is not likely to substantially reduce southern red oak acorn establishment. Compared to post and southern red oak, however, white oak acorns are very sensitive to flooding. Ten days of flooding reduced germination appreciably, and 20 days of flooding almost eliminated any possibility of germination. Bell (1975) also found that acorn germination of white oak was severely limited by 15 days of flooding. This sensitivity may be caused by the characteristic that white oak acorns germinate soon after they fall to ground. In this study, most acorns germinated during stratification. Increased metabolism within the acorns apparently made them susceptible to flooding. Martin and others (1991) pointed out that increased anaerobic metabolism can damage seeds through the buildup of toxic materials.

Although germination of southern red oak acorns was reduced significantly after 20 days of flooding in this study, different results were reported by Larsen (1963) who tested the effects of water soaking for up to 8 weeks on acorn germination of southern red oak, willow oak, laurel oak (*Q. laurifolia* Michx.), and overcup oak (*Q. lyrata* Walt.). Flooding did not affect germination of southern red and willow oak acorns, and both species had germination rates between 40 and 45 percent. The response of willow oak acorns to flooding is similar to that found in this study. However, the germination of southern red oak acorns without flooding in Larsen's study was much lower than that in our study, which may indicate considerable variation among the seed lots.

For upland species, the embryo axes of acorns were most severely damaged by flooding. Guo and others (1998) found similar damage for black and northern red oak acorns. However, radicles or roots often developed from the connective tissue between the embryo axis and the cotyledons, especially for white oak acorns. Some of the radicles and roots were still alive after 30 days of flooding and the 60-day germination test even though the embryo axes were apparently dead. However, no seedlings developed from the flood-damaged acorns because of the dead embryo axes.

One factor that affects distribution of species is flooding on alluvial sites. Tree seeds must be able to withstand flooding before seedlings can occupy alluvial sites. Cherrybark and willow oaks apparently have no problem becoming established on sites with spring flooding of up to 30 days. They may withstand additional flooding but further research is needed to confirm this. An interesting finding of our study is the tolerance of the post oak acorns to flooding. Post oak typically grows on dry sites on upper slopes (Stransky 1990), yet its acorns showed a fairly high tolerance to flooding. It is likely that the exclusion of this species on alluvial sites is due to some other factor than damage of acorns by flooding.

REFERENCES

Allen, J.A.; Kennedy, H.E., Jr. 1989. Bottomland hardwood reforestation in the lower Mississippi valley. Slidell, LA: U.S. Department of Interior, Fish and Wildlife Service, National Wetland Research Center; and Stoneville, MS: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 28 p.

Bell, D.T. 1975. Germination of *Quercus alba* L. following flood conditions. For. Res. Rep. 75-2. Urbana-Champaign, IL: University of Illinois, Department of Forestry. 4 p.

Bonner, F.T. 1974. Maturation of acorns of cherrybark, water, and willow oaks. Forest Science. 20: 238-242.

Bonner, F.T. 1996. Responses to drying of recalcitrant seeds of *Quercus nigra* L. Annals of Botany. 78: 181-187.

Briscoe, C.B. 1961. Germination of cherrybark and Nuttall oak acorns following flooding. Ecology. 42: 430-431.

Guo, Y.; Shelton, M.G.; Lockhart, B.R. 1998. Effects of flood duration and season on germination of black, cherrybark, northern red, and water oak acorns. New Forest. 15: 69-76.

Hodges, J.D.; Switzer, G.L. 1979. Some aspects of the ecology of southern bottomland hardwoods. In: North America's forests: gateway to opportunity. Joint Convention of the Society of American Foresters and the Canadian Institute of Forestry. 1978 October 22-26. St. Louis, MO: Washington, DC: Society of American Foresters: 360-365.

Hook, D.D. 1984. Waterlogging tolerance of lowland tree species of the South. Southern Journal of Applied Forestry. 8: 136-149.

Kramer, P.J.; Kozlowski, T.T. 1979. Physiology of woody plants. New York, NY: Academic Press. 811 p.

Krinard, R.M. 1990. Cherrybark oak. In: Burns R.M.; Honkala B.H. (eds.). Silvics of North America. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture: 644-649.

Larsen, H.S. 1963. Effects of soaking in water on acorn germination of four southern oaks. Forest Science. 9: 236-241.

Martin, B.A.; Cerwick, S.F.; Reding, L.D. 1991. Physiological basis for inhibition of maize seed germination by flooding. Crop Science. 31: 1052-1057.

Norton, C.R. 1986. Germination under flooding: metabolic implications and alleviation of injury. HortScience. 21: 1123-1125.

SAS Institute Inc. 1986. SAS user's guide: statistics. 5th edition. Cary, NC. 956 p.

Schlaegel, B. E. 1990. Willow oak. In*:* Burns R.M.; Honkala B.H. (eds.). Silvics of North America. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture: 715-720.

Stransky, J.J. 1990. Post oak. In: Burns R.M.; Honkala B.H. (eds.). Silvics of North America. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture: 738-743.

Ecophysiology

Moderator:

MARY ANN SWORD
USDA Forest Service

WATER RELATIONS AND GAS EXCHANGE OF LOBLOLLY PINE SEEDLINGS UNDER DIFFERENT CULTURAL PRACTICES ON POORLY DRAINED SITES IN ARKANSAS

Mohd S. Rahman, Michael G. Messina, and Richard F. Fisher[1]

Abstract—Substantial forest acreage in the south-central U.S. is seasonally water-logged due to an underlying fragipan. Severely restricted drainage in the non-growing season leads to a reduced subsoil zone, which restricts root respiration. The same sites may also be subjected to summer drought. These climatic and edaphic problems may result in low seedling survival and reduced growth. To address these issues, we established ten research sites in southern Arkansas. Six sites in an incomplete factorial design were established in 1999, each with four bedded treatments: 1) control (no subsequent treatment), 2) fertilized during the first two years after planting, 3) complete weed control until canopy closure, and 4) complete weed control and continuous fertilization as per foliar analysis; and two non-bedded treatments: 1) control and 2) fertilization and complete weed control in the first year. Water relations data (diurnal water potential, stomatal conductance, and transpiration) and net CO_2 assimilation were collected during the 1999 and 2000 growing seasons. This paper will include data from the 2000 growing season. Results to date show improved water relations and gas exchange from intensive culture.

INTRODUCTION

There is a substantial acreage of seasonally wet, somewhat poorly drained sites in the Western Gulf. These sites experience standing water through much of the winter due to an underlying fragipan. This results in an anaerobic atmosphere for roots and subsequent poor seedling survival. The condition may also assist in nutrient leaching loss to the subsoil fragipan. The sites also experience summer drought which may contribute to reduced growth. Mechanical site preparation and early cultural treatment can affect pine growth on flatwoods (Lauer and Glover 1998, Shiver and Rheney 1990). Therefore, our research objectives was to test the efficacy of several cultural practices for ameliorating adverse site conditions.

MATERIALS AND METHODS

The research was designed to investigate three treatment factors: mechanical site preparation, fertilization and chemical vegetation control. Treatments tested in an incomplete factorial design were: two levels of mechanical site preparation (no preparation, and bedded and ripped), three levels of chemical vegetation control (no control and chemical control during the first year, and complete vegetation control until canopy closure), and three levels of fertilization (none, fertilization during the first year, and continuous fertilization until desired nutrient foliar concentration was achieved). Six of the 18 possible treatment combinations were established at each of six sites in southern Arkansas:

— Bedding control (BED-N)
— Bedding + complete chemical vegetation control (BED-CV)
— Bedding + continuous fertilization (BED-F)
— Bedding + complete chemical vegetation control + continuous fertilization (BED-CVF)
— Flatplanting control (FP-N)
— Flatplanting + chemical vegetation control in the first year + fertilization in the first year (FP-VF)

Spacing was uniform in any site, but varied among sites to 1.8-2.4 meters between trees on the row/bed and 3.3-4.0 meters between rows/beds. All sites were planted with loblolly pine (*Pinus taeda* L.) in January 1999. A whole plot was 13 rows X 18 trees, of which the central 7 rows X 10 trees were used for measurement giving a three-row buffer on each side and a four-tree buffer on each end. The whole plot covered an area of about 0.40 hectare.

Mechanical Site Preparation

All sites were initially prepared by shearing and burning, followed by a combination plow with a ripping tine and bedding disks, except for the non-bedded plots.

Fertilization

Fertilized plots were treated in a broadcast manner with 280 kilograms per hectare of diammonium phosphate, 140 kilograms per hectare of potassium chloride, and 112

[1]Graduate Student, Professor,Department of Forest Science, Texas A&M University, College Station, TX 77843-2135; Temple-Inland Forest Products Corporation, P.O. Drawer N, Diboll, TX 7594, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Soil volumetric moisture content ($cm^3\ cm^{-3}$) of six treatments, bedded (BED) and flatplanted (FP), treated with fertilizer alone (F), complete vegetation control (CV), complete vegetation control and continuous fertilization (CVF), vegetation control and fertilization during year of planting (VF), and control or check (N). Numbers followed by the same letter within columns are not statistically different (alpha = 0.05)

Site Prep	Treatment	June 8	August 18
FP	N	6.9 c	4.9 c
FP	VF	9.8 a	8.0 a
BED	N	6.7 c	4.1 d
BED	F	6.2 c	4.1 d
BED	CV	10.3 a	7.1 b
BED	CVF	8.2 b	5.5 c

kilograms per hectare of a mix of calcium, magnesium, boron, and manganese.

Chemical Vegetation Control

All plots to be treated with herbicide were sprayed with glyphosate and sulfometuron in 1999 and imazapyr and sulfometuron in 2000. Herbicides were applied with backpack sprayers at recommended rates. To ensure a complete vegetation control, plots were resprayed as necessary.

Data Collection

Data were collected throughout the 1999 and 2000 growing seasons. Volumetric soil moisture content was determined using time-domain reflectometry during sampling sessions for water relations at three different locations within each plot at all measurement hours. Diurnal water potential data were collected using a pressure bomb apparatus on three seedlings per plot at 0900, 1200, 1500 and 1800 hours. The same seedlings were used for all measurement hours and also for other measurements such as stomatal conductance, transpiration and vapor pressure deficit, which were measured using a LiCor 6200. In addition, net CO_2 assimilation rate, intercellular CO_2 concentration and incoming irradiance were measured using a LiCor 6250 for the same seedlings concurrent with the other measurements.

RESULTS AND DISCUSSION

Data will be presented from one of the six sites measured, that being located near Crossett. The soil series there is a Calloway silt loam, a fine-silty, mixed, active, thermic Aquic Fragiudalf. The depth of the subsoil fragipan ranges between 50 and 60 centimeters. Data were collected on two 2000 sampling sessions, once at the beginning of the summer (June 8) and again at the end of the summer (August 18). Air temperatures, averaged throughout the day, for these two sampling sessions were 34.8 and 35.1 °C, respectively. Cumulative precipitation for the 14 days preceding June 8 was 6.68 centimeters of which 5.41 centimeters fell in the previous seven days. There was no

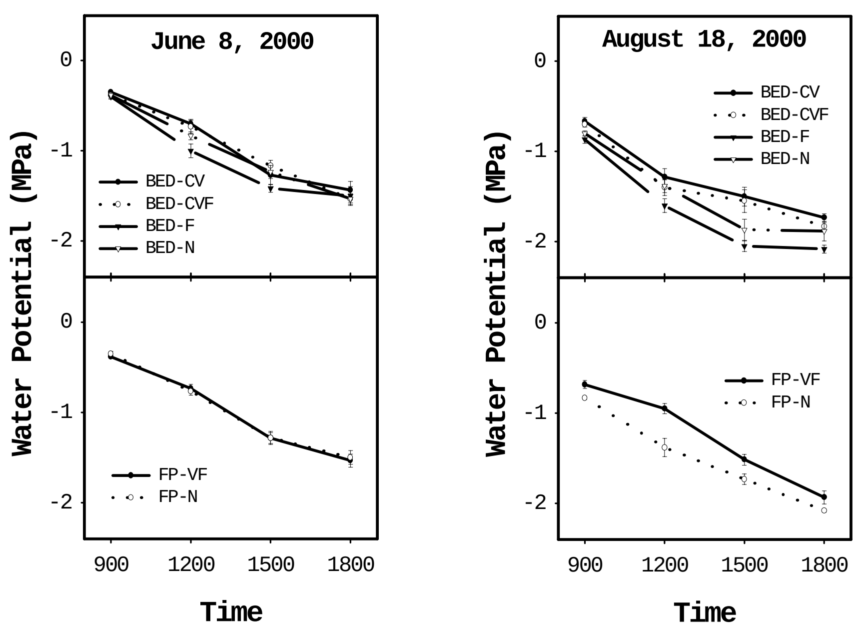


Figure 1—Needle water potential of loblolly pine seedlings during two sampling sessions from four different treatments on bedded plots: control (BED-N), continuous fertilization (BED-F), complete vegetation control (BED-CVF), and complete vegetation control and continuous fertilization (BED-CVF); and two flat-planted plots: control (FP-N) and fertilization and weed control in year of planting (FP-VF). Vertical bars indicate one standard error on each side of symbol.

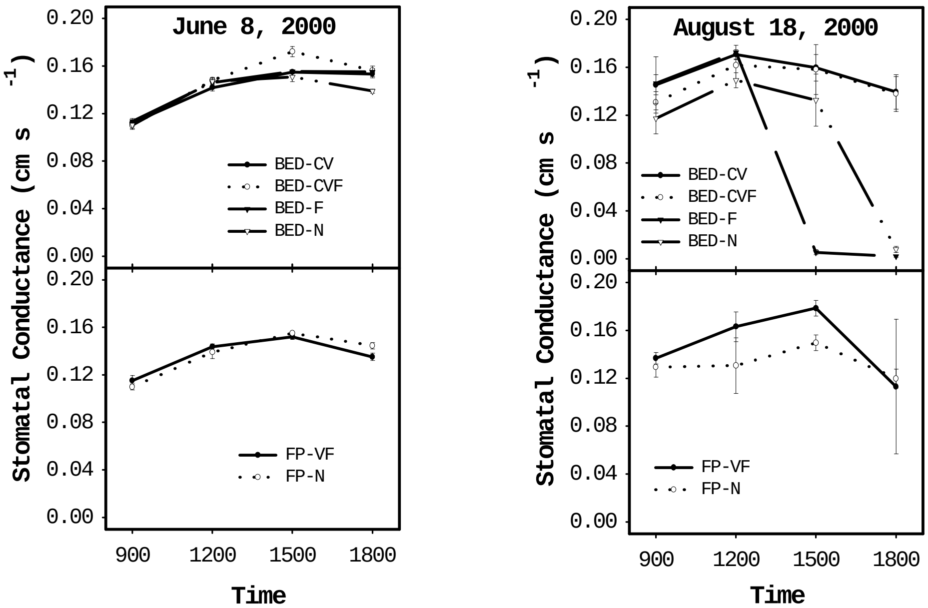


Figure 2—Stomatal conductance of loblolly pine seedlings during two sampling sessions from four different treatments on bedded plots: control (BED-N), continuous fertilization (BED-F), complete vegetation control (BED-CVF), and complete vegetation control and continuous fertilization (BED-CVF); and two flat-planted plots: control (FP-N) and fertilization and weed control in year of planting (FP-VF). Vertical bars indicate one standard error on each side of symbol.

rainfall in the four days immediately preceding data collection. There was no rainfall recorded in the 14 days preceding the August 18 sampling session.

Volumetric Soil Moisture Content

Soil volumetric moisture content was higher for all plots with chemical vegetation control (table 1). There was more water available on June 8 for all treatments than on August 18, reflecting prolonged drought as summer progressed. Bedding decreased soil water availability in summer as there was less water available in the bedded treatments than in flatplanted treatments. For example, soil volumetric moisture content on August 18 for the flatplanted-continuous vegetation control-fertilized treatment was 8.0 percent, whereas for the same treatment on a bedded plot is was only 5.5 percent. Although bedding can enhance early seedling survival, it can also decrease soil water availability during summer drought from enhanced subsoil drainage. Fertilization also affected soil volumetric moisture content when combined with certain site preparation and herbicide treatments (table 1). On bedded treatments, fertilized plots had lower volumetric soil moisture contents when competing vegetation was controlled on both sampling dates (BED-CV vs. BED-CVF). However, the combination of complete vegetation control and fertilization increased soil moisture content on flat-planted plots (FP-N vs. FP-VF). Fertilization alone did not affect soil moisture content on bedded plots (BED-N vs. BED-F). These results seem counterintuitive in that fertilization without competition control would be expected to promote prolific herbaceous plant growth with a consequential decrease in soil moisture. Herbicide application would be expected to diminish this effect. However, the opposite results were observed for which no clear explanation can be offered.

Needle Water Potential

Needle water potential on June 8 was comparable for BED and FP treatments (figure 1). Even though the BED-F treatment had lower water potential at 1200 and 1500 hours compared to the other treatments, it showed comparable water potential at 1800 hours. Needle water potential in the early morning was very high for all treatments and decrease throughout the day linearly, but never went below –1.8 MPa. However, there was a strong treatment difference in needle water potential on August 18. Seedlings from all treatments showed a lower water potential compared to June, starting with a lower early water potential and decreasing to as low as –2.1 MPa at the end of the day, thereby reflecting a moderate to severe water stress (Fitter and Hay 1987, Seiler and Johnson 1988). Seedlings from plots treated with herbicide showed higher water potential indicating that improved plant water relations were obtained from chemical vegetation control by means of increased soil water availability (figure 1).

Stomatal Conductance

Stomatal conductance did not vary between flatplanted plots during the June sampling session (figure 2). On bedded plots, all treatments started to conduct water in a comparable manner early in the day, but seedlings in the BED-N treatment conducted less by the end of the day. Stomatal conductance for all treatments, bedded and flatplanted, increased to a maximum at 1500 hours and then decreased at 1800 hours. There was a strong treatment effect on August 18 on stomatal conductance for all treatments (figure 2). Seedling stomatal conductance for the FP-VF plot was higher for 1200 and 1500 hours than the FP-N. However, the lower stomatal conductance at 1800 hours for FP-VF was due to one sample which

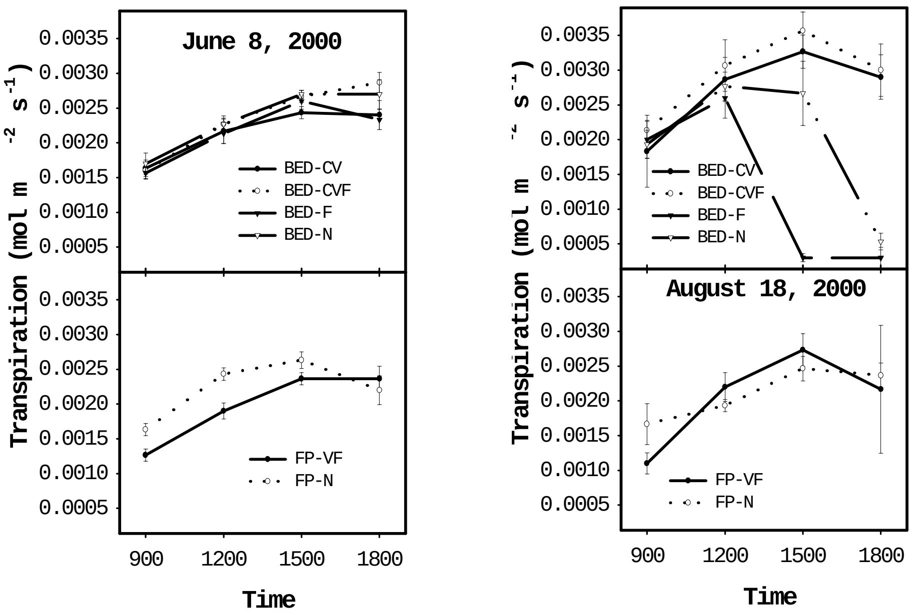


Figure 3—Transpiration of loblolly pine seedlings during two sampling sessions from four different treatments on bedded plots: control (BED-N), continuous fertilization (BED-F), complete vegetation control (BED-CVF), and complete vegetation control and continuous fertilization (BED-CVF); and two flat-planted plots: control (FP-N) and fertilization and weed control in year of planting (FP-VF). Vertical bars indicate one standard error on each side of symbol.

showed stomatal conductance as low as zero presumably due to stomatal closure, resulting in a high standard error for that treatment at that hour. Stomatal conductance for the BED-F ceased after 1500 hours and for BED-N at 1800 hours. Seedlings with water potential lower than –1.8 MPa ceased stomatal conductance.

Transpiration

Transpiration was similar among bedded treatments for most hours on June 8, although there was a treatment difference at 1500 and 1800 hours with BED-CVF transpiring most water (figure 3). Transpiration for the FP-N treatment was significantly (alpha=0.05) higher than for FP-VF until 1500 hours after which it was comparable. Transpiration did not vary between flat-planted treatments on August 18. However, transpiration followed a pattern similar to that for stomatal conductance for bedded treatments on August 18 (compare figures 2 and 3), reflecting that transpiration was controlled by stomatal behavior for this sampling session during this time of severe drought.

Net Photosynthesis

Net CO_2 assimilation rate (i.e., photosynthesis) did not vary between flatplanted plots on June 8, although it varied slightly within the bedded plots with fertilized plots being higher than the N and CV (figure 4). Photosynthesis was strongly affected by stomatal behavior on August 18 when treatments with no stomatal conductance showed no net CO_2 assimilation; BED-FP after 1500 hours and BED-N after 1800 hours (compare figures 2 and 4).

CONCLUSIONS

There was a strong influence of treatments on seedling water relations and photosynthesis. This was more obvious in the late summer after a droughty summer. Chemical vegetation control played a key role in maintaining improved seedling water relations. However, fertilization helped to enhance net CO_2 assimilation and at a time of severe water stress, there was a continuing CO_2 assimilation due to reduced competition from chemical vegetation control. Even though bedding did result in decreased soil water availability later in the growing season, comparable water relations between seedlings on bedded and flatplanted sites suggest increased root growth in seedlings on bedded plots.

ACKNOWLEDGMENTS

We thank the following for financial support: International Paper Company, Potlatch Corporation, The Timber Company, Oak Ridge National Laboratory, and the Department of Energy. We also thank the following scientists for intellectual contributions to study design and maintenance: Nick Chappell, Marshall Jacobson, Conner Fristoe, Chuck Hollis and Mark Hebert.

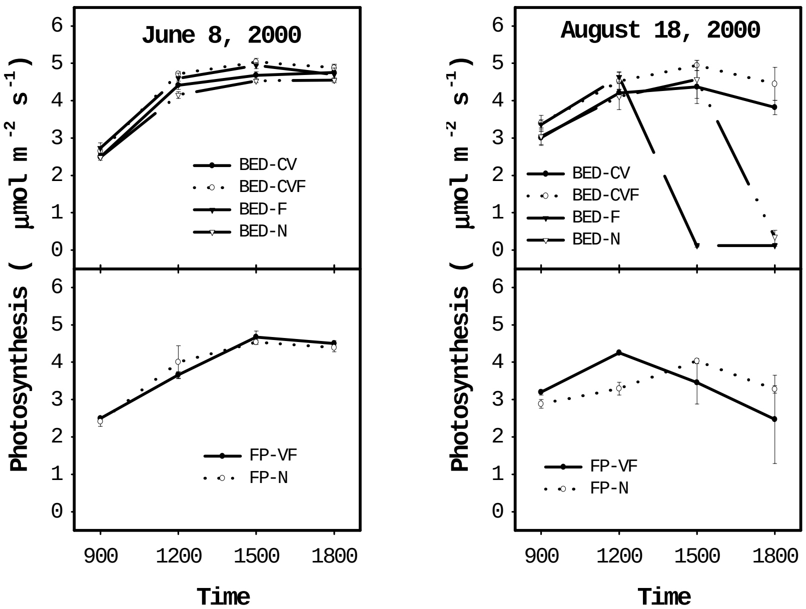


Figure 4—Net CO_2 assimilation (photosynthesis) of loblolly pine seedlings during two sampling sessions from four different treatments on bedded plots: control (BED-N), continuous fertilization (BED-F), complete vegetation control (BED-CVF), and complete vegetation control and continuous fertilization (BED-CVF); and two flat-planted plots: control (FP-N) and fertilization and weed control in year of planting (FP-VF). Vertical bars indicate one standard error on each side of symbol.

REFERENCES

Fitter, A. H.; R. K. M. Hay. 1987. Environmental physiology of plants. 2d Ed. San Diego, CA: Academic Press.

Lauer, D.K.; G.R. Glover. 1998. Early pine response to control of herbaceous and shrub vegetation in the flatwoods. Southern Journal Applied Forestry. 15(4): 201-208.

Seiler, J.R.; J.D. Johnson. 1988. Physiological and morphological responses of three half-sib families of loblolly pine to water-stress conditioning. Forest Science. 34(2): 487-495.

Shiver, B. D.; J. W. Rheney. 1990. Site-preparation method and early cultural treatments affect growth of flatwoods slash pine plantations. Southern Journal of Applied Forestry. 14(4): 183-188.

GPP IN LOBLOLLY PINE: A MONTHLY COMPARISON OF EMPIRICAL AND PROCESS MODELS

Christopher Gough, John Seiler, Kurt Johnsen, and David Arthur Sampson[1]

Abstract— Monthly and yearly gross primary productivity (GPP) estimates derived from an empirical and two process based models (3PG and BIOMASS) were compared. Spatial and temporal variation in foliar gas photosynthesis was examined and used to develop GPP prediction models for fertilized nine-year-old loblolly pine (*Pinus taeda*) stands located in the North Carolina Sandhills. Foliar gas exchange in both the upper and lower thirds of crowns was monitored monthly for a year. Based on these data, empirical models were developed for the growing and non-growing seasons and upper and lower crown levels. Common empirical models include the variables photosynthetically active radiation (PAR), Ln(PAR), and VPD. Statistical differences in model estimates for crown positions and for both the growing and non-growing seasons indicated that the use of separate empirical models was appropriate for GPP estimations, yet simulated light-response curves yield similar rates. Monthly GPP estimates derived from empirical models were compared with process model predictions. Average monthly environmental data were applied to models to estimate GPP. Both process models predicted a greater relative GPP during the growing season (80 percent) compared with the empirical model (65 percent), while the opposite trend was apparent for the non-growing season. Monthly GPP variability was greater in the 3PG and BIOMASS predictions, appearing to reflect monthly temperatures and stand growth, while the empirical analysis predicted a relatively high contribution to yearly GPP during the non-growing season. Predicted GPPs for the entire year were 192.8, 142.8, and 192.4 mol C/m^2 for the empirical, BIOMASS, and 3PG models, respectively.

INTRODUCTION

Gross primary productivity (GPP) is a measure of the potential carbon gain by a stand prior to respiratory losses. GPP can not be measured directly and therefore must be estimated using models developed to predict the total carbon yield or biomass accumulation prior to respiration. Process models have become increasingly important and useful in assessing stand productivity since they integrate several biological functions that directly define the growth potential of a tree and ultimately the stand (Johnson and others 2001).

3PG and BIOMASS are photosynthesis-stomatal conductance process models, which integrate physiological plant responses, ecological processes, and physical relationships within the stand to predict stand growth. Both have been calibrated for loblolly pine. 3PG and BIOMASS primarily utilize quantum efficiency and maximum carbon assimilation rate (Amax) to predict carbon fixation rates. An extensive overview of 3PG and BIOMASS is provided by Landsberg and others 2001 (3PG), Landsberg and Waring 1997 (3PG), McMurtie and Landsberg 1992 (BIOMASS). Solar radiation, atmospheric vapor pressure deficit (VPD), rainfall, frost days per month, and average temperature are input drivers used in 3PG calculations. Additionally, a fertility rating is used to adjust the simulated photosynthesis light-response curve in 3PG. BIOMASS uses shortwave radiation, VPD, minimum and maximum daily temperatures, and precipitation. BIOMASS and 3PG essentially calculate GPP based on the amount of absorbed PAR at the canopy level by converting light energy into carbon fixation potential. Other environmental inputs alter the efficiency and rate of carbon fixation at the canopy level.

Process models are rarely evaluated to determine if predicted GPPs reflect actual physiological data collected from a stand. The collection of gas exchange data over an entire year provided the unique opportunity to develop seasonal empirical photosynthesis models that could be used to validate process model GPP outputs. The two objectives of this study were (i) to compare monthly predicted GPP in a loblolly pine stand using two process models (3PG and BIOMASS) and an empirical model developed from gas exchange date collected from the same stand and (ii) to compare total yearly predicted GPP using the same models.

[1]Graduate Student and Professor, Virginia Tech Department of Forestry, 228 Cheatham Hall, Blacksburg, VA 24061; Project Leader, USDA Forest Service, Research Scientist, Virginia Tech Department of Forestry, P.O. Box 12254, Cornwallis Rd., Research Triangle Park, NC 27709, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

METHODS

Study Site

Photosynthesis measurements for empirical model development were taken in Scotland County, North Carolina (35°N lat., 79°W long.) at the United States Forest Service (USFS) Southeastern Forest Tree Experiment and Education Site (SETRES). The stand consists of hand planted loblolly pine (2 x 3 m spacing) established in 1985 (14 years old at the beginning of the study). The site is flat, infertile, excessively drained, sandy, siliceous, and composed of thermic Psammentic Hapludult soil (Wakulla series). The average annual precipitation is 121 cm, but drought is common in the summer and early fall. The average summer temperature is 26°C and the winter average is 9°C. The average annual temperature is 17°C. The climate is humid and temperate with hot summers and mild winters, allowing for over a six month growing season. The native forest cover type is Longleaf Pine-Scrub Oak. The established site study design is a 2 x 2 factorial combination of fertilized and irrigated additions replicated four times. The plots consist of 30 x 30 m measurement plots within 50 x 50 m treatment plots. Interaction among below ground matter from adjacent plots is prevented by a 150 cm deep plastic liner that separates plots. Non-pine vegetation is controlled by mechanical and chemical (glyphosate) treatments such that no understory vegetation exists. Nutrient applications began in March 1992 and continued through March 1998. The total amount of each nutrient (in Kg/Ha) added over the six year period is as follows: N (777), P (151), K (337), Ca (168), Mg (164), S (208), and B (3.9). In the fertilized plots, crown closure is common. Total biomass accumulation at SETRES increased 91 percent four years after initial fertilization treatments began (Albaugh and others 1998).

Photosynthesis Measurements

Photosynthesis was measured monthly in fertilized plots from April 1999 to March 2000 at SETRES using the LiCor 6400 Portable Photosynthesis System (LiCor, Lincoln, NE). Fertilized plots were chosen over other treatments because the fertilized stands most closely represent intensively managed loblolly pine forests (since fertilization is common and irrigation is not). Photosynthesis rates from upper and lower crown cut foliage were measured (Ginn and others 1991) from a subsample of 2 trees per block for a total of 16 measurements (4 blocks x 2 crown positions x 2 subsamples). Gas exchange was measured in each block sequentially, and subsamples from each level were chosen randomly for sampling. Blocks were always measured in the same order. This sequence was repeated three times on each measurement day in order to capture an abbreviated diurnal response to daily environmental changes. Measurements included morning (9 AM), afternoon (11:30 AM), and late afternoon (1:30 PM) measurement periods. A total of 48 measurements (three sampling sequences) in fertilized plots were generally taken throughout the day.

Shoots were cut using a pole pruner and measurements were taken immediately on a detached fascicle. All measurements were taken at the ambient temperature and humidity, and CO_2 concentrations were held constant in the chamber at 350 ppm. The average PAR was estimated for the upper and lower third of crowns and kept constant in the measurement chamber (using the LiCor's actinic source) for each crown level in the block throughout a measurement period. The PAR for each crown level was determined by evaluating the average PAR in full sunlight (for the upper third) and the average PAR in the understory (for the lower third) prior to the measurement period. The PAR was reassessed and adjusted for each measurement period according to the PAR levels immediately prior to sampling. Water potentials were determined for the same branch as the sample immediately after being cut using a field pressure chamber (PMS instrument Co., Corvallis, OR). All measurements were completed in one day. Needle diameter was immediately recorded and leaf area was later determined using the following equation (Ginn and others 1991):

$$LA_1 = (n * l * d) + (p * d * l)$$

where l = the length of the needle, d = fascicle diameter and n = number of needles in the fascicle. Values were adjusted to represent gas exchange on a per leaf area basis. Foliar nitrogen percentages of measured needles were obtained from pooled samples collected from each block/crown position combination during eight of the twelve months using a Carla ERBA (Raleigh, NC).

Empirical Model Development

Empirical models were developed using multiple linear regression techniques in SASä. (SAS Statistical Institute, Cary, NC). Common simplified gas exchange models for crown positions were developed for the growing (April – October) and non-growing (November – March) seasons. Common models include the variables PAR, ln(PAR), and VPD. Air temperature, stem water potential, relative humidity, and foliar nitrogen contents were not significant model variables. Statistical comparisons of seasonal and crown position model parameter estimates revealed that significant differences exist among all models. Therefore, models for the upper and lower crowns within the growing and non-growing seasons were used to estimate GPP.

GPP Analysis

Monthly GPP was predicted using the empirical models, 3PG, and BIOMASS. 3PG was originally calibrated for loblolly pine at SETRES (Landsberg and others 2001). Average environmental data for a 20-year period at SETRES was used to calculate GPP in 3PG, while BIOMASS utilized 1995-1996 environmental data from SETRES. 3PG outputs data in a monthly time-step while BIOMASS provides a daily time-step output. Daily BIOMASS outputs were summed for each month. Upper and lower PAR and leaf area index (LAI) for three canopy layers were estimated using BIOMASS. The middle layer was divided in half and added equally to both the upper and lower layers for the empirical estimates of GPP.

RESULTS AND DISCUSSION

Actual mean monthly photosynthesis measured at SETRES remained relatively high during the non-growing season with significantly greater rates occurring in the upper crown compared to the lower crown during all

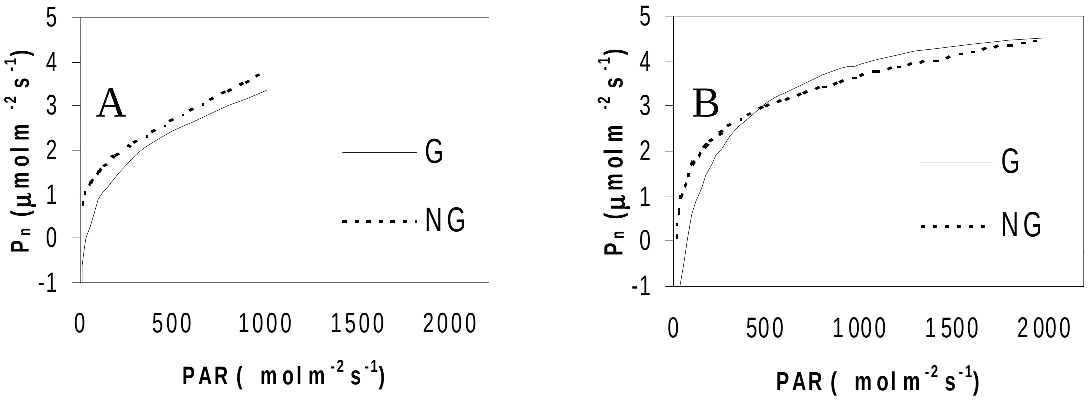


Figure 1—Simulated light response curves for the lower crown (A) and the upper crown (B) for both the growing and non-growing seasons.

months ($p<0.05$) (figure 1). Mean rates in January and February were higher than those recorded in June and largely reflect the cloudy conditions on the June measurement day. High photosynthesis rates at SETRESII (an adjacent sister experimental station) have been recorded during the non-growing season as well (unpublished data).

As mentioned before, statistical tests revealed that significant differences exist among parameter estimates of photosynthesis prediction models developed for the growing and non-growing seasons and the upper and lower crowns (table 1). However, predicted light response curves for the growing and non-growing seasons within a crown level are similar, implying that the photosynthetic response to light and the ability to fix carbon does not greatly differ with season (figure 2). This is reflected in the monthly empirical GPP predictions for the upper and lower crowns (figure 3), which suggest that GPP is reduced by only a third in the winter months relative to the peak July rate. Monthly BIOMASS predictions exhibit a lower relative GPP accumulation during the winter months and a greater accumulation during the growing season (figure 4A), suggesting that BIOMASS is sensitive to low temperatures. This is reflected in daily BIOMASS outputs in which a GPP of zero was predicted for days below freezing (data not shown). 3PG predicts a rapid increase from January through May, followed by more erratic monthly values (figure 4B). This behavior is primarily due to the density induced mortality function incorporated into the process model (Landsberg and others 2001).

The BIOMASS and 3PG models predict that 80 percent of the yearly GPP accumulates during the growing season and 20 percent accumulates during the non-growing season. The empirical model predicts that 65 percent and 35 percent of the GPP is distributed between the growing and non-growing seasons, respectively (figure 5A).

Table 1—Significant variables, Parameter estimates, and total R^2 values for common photosynthesis prediction models developed for the upper and lower crowns and the growing and non-growing seasons in fertilized stands at SETRES. All parameter estimates were statistically different ($p<0.1$)

Lower Crown			Upper Crown		
Growing Season					
Parameter	Estimate	R^2	Parameter	Estimate	R^2
Intercept	-1.802	0.59	Intercept	-5.542	0.60
PAR	7.237×10^{-4}		PAR	5.477×10^{-4}	
Ln(PAR)	0.7912		Ln(PAR)	1.653	
VPD	-0.5238		VPD	-0.6983	
Non-Growing Season					
Intercept	-0.4707	0.63	Intercept	-2.048	0.62
PAR	0.001816		PAR	3.670×10^{-4}	
Ln(PAR)	0.2684		Ln(PAR)	0.7066	
VPD	0.2911		VPD	0.2356	

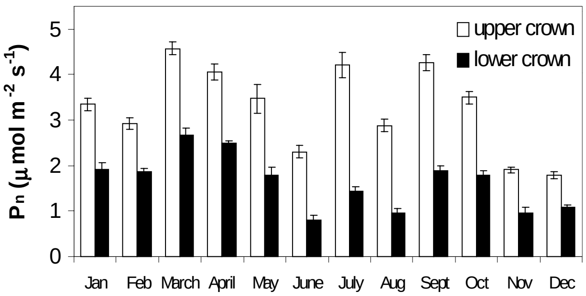


Figure 2—Mean monthly photosynthesis rates for 1999-2000 measurements in upper and lower crown foliage at SETRES. Photosynthesis was significantly greater in the upper crown for all months ($p<0.1$).

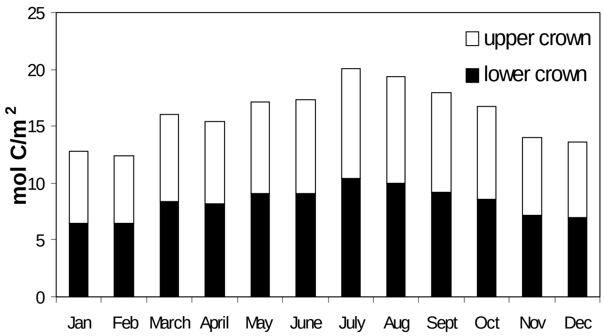


Figure 3—Empirically derived predictions of monthly GPP in the upper and lower crowns.

Absolute predicted GPPs during the growing season are fairly similar for the empirical model and BIOMASS (about 120 mol C/m^2), while 3PG predicts a much higher value (160 mol C/m^2) (figure 5B). During the non-growing season, both 3PG and BIOMASS predict lower actual values compared with the empirical model. Thus, in relative terms (figure 5A) the process models may overpredict GPP during the growing season and underpredict GPP during the non-growing season. In absolute terms (figure 5B), only 3PG predicts greater GPP during the growing season when compared with the empirical predictions. 3PG is calibrated using field growth and biomass measurements; therefore, the model may not accurately account for the potential carbon gain in the winter if photosynthate does not immediately contribute to growth. Evidence exists that labile carbon pools accumulate in loblolly pine during the winter and are utilized during high stress situations in the summer when carbon fixation is limited and does not meet the metabolic or growth requirements of the tree (Sampson and others 2001).

Thus, winter GPP may not result in immediate measurable growth. Seasonal 3PG estimates probably more closely parallel growth data while the empirical analysis directly reflects carbon fixation estimates. This is consistent with growth data collected from SETRES in which a majority of measurable stem wood production is observed during the growing season (unpublished data).

Interestingly, the cumulative predicted GPPs for the year are fairly similar among the empirical (192.8 mol C/m^2), BIOMASS (142.9 mol C/m^2), and 3PG (192.4 mol C/m^2) models. Again, 3PG was calibrated for loblolly pine at SETRES, which is where data was collected for empirical model development. This may explain why the yearly total is similar for the two models since 3PG was calibrated against actual field biomass data and the empirical model is likely a good estimate of GPP based on actual physiological measurements of carbon fixation on the site over a year. 3PG and the empirical models used different data collected at SETRES and represent two modeling approaches. The fact that they arrive at similar cumulative predicted GPPs validates both models on a yearly scale.

These results indicate that the process models do not fully account for winter acclimation and summer declines. 3PG

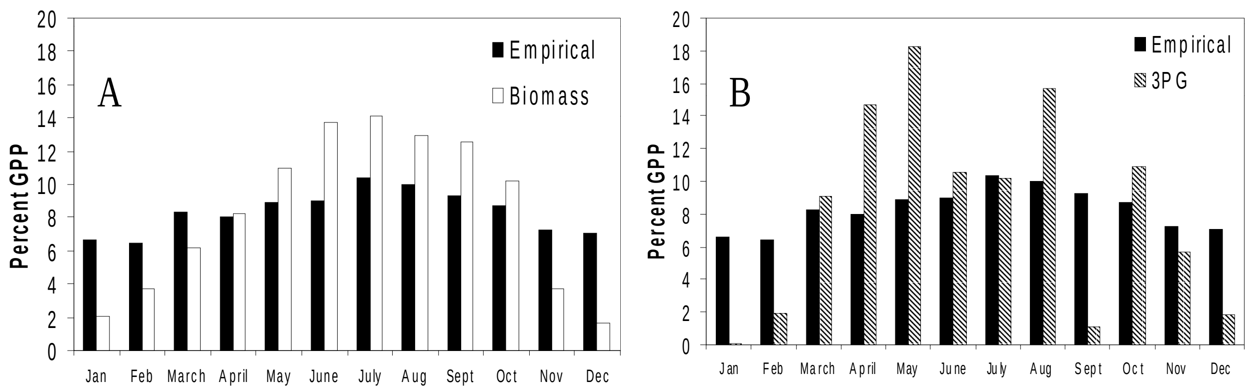


Figure 4—Percent monthly GPP contributions relative to yearlong totals for empirical and BIOMASS predictions (A) and empirical and 3PG predictions (B).

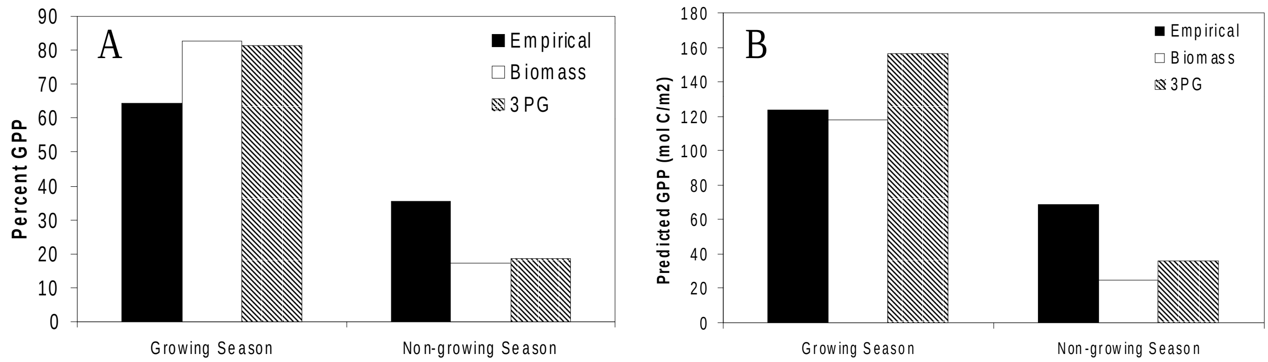


Figure 5—Empirical, BIOMASS, and 3PG estimates of percent GPP contribution (A) and actual predicted GPP (B) for the growing (April-October) and non-growing (November-March) seasons.

and BIOMASS have critical temperature thresholds (Landsberg and others 2001 (3PG), McMurtie and Landsberg 1992), which may result in oversensitivity when the environmental data are averaged, especially when average temperatures are skewed by a few instances of extremely low or high temperatures. During the summer, higher predicted GPPs by process models relative to the empirical model could be explained by a lower sensitivity to VPD. The empirical estimates show approximately a 25 percent decline due to high VPDs in the summer (figure 6), which is similar to the actual difference in predicted GPPs between the empirical and process models during the growing season (figure 5B).

The empirical approach to predicting GPP provides reasonable estimates - at least for SETRES. Scaling up of the empirical model to the stand level at other locations may possibly be achieved by taking into account factors that drive total carbon fixation and ultimately GPP. LAI is an excellent indicator of potential productivity (Teskey and others 1987, Teskey and others 1994, Vose and Allen 1988) and highly reflective of site fertility (Gillespie and others 1994, Albaugh and others 1998). Reported crown leaf area estimates for loblolly pine in Hawaii were five times greater than stands examined in coastal South Carolina at 25 years (Harms and others 1994). Greater crown leaf areas paralleled higher total biomass estimates in Hawaiian loblolly pine. Therefore, leaf area may be an excellent indicator of site productivity and substitute for fertility ratings that are required inputs in process models and are often difficult to determine (Landsberg and others 2001). Leaf area is directly related to GPP since total crown carbon fixation is enhanced with the increase in photosynthetic machinery. This of course is only the case when the assumption is made that greater fertility does not directly affect the photosynthetic capacity or efficiency of an individual leaf. Incident radiation and day-length, and density-induced mortality would also have to be accounted for in order to expand the inference space of empirical estimates to include other sites.

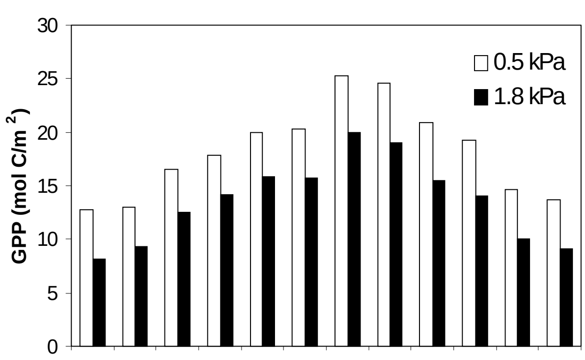


Figure 6—The effect of high and low VPD on empirically predicted GPP. The selected VPDs represent the high and low monthly averages recorded at SETRES.

ACKNOWLEDGMENTS

We would like to thank the USDA Forest Service for financial support. Pete Anderson, Lance Kress, John Butnor, and Chris Maier from the USFS Southern Research Station, and John Peterson, Luke McCall, and Robert Pangle from Virginia Tech provided field and/or technical assistance.

REFERENCES

Albaugh, T.J.; Allen, H.L.; Dougherty, P.M.; Kress, L.W.; King, J.S. 1998. Leaf area and above- and belowground growth responses of loblolly pine to nutrient and water additions. Forest Science. 44: 1-11.

Gillespie, A.R.; Allen, H.L.; Vose, J.M. 1988. Amount of vertical distribution of foliage of young loblolly pine trees as affected by canopy position and silvicultural treatment. Canadian Journal of Forestry Research. 24: 1337-1344.

Ginn, S.E.; Seiler, J.R.; Cazell, B.H.; Kreh, R.E. 1991. Physiological and growth responses of eight-year-old loblolly pine stands to thinning. Forest Science. 37(4): 1030-1040.

Johnsen, K.; Samuelson, L.; Teskey, R.; McNulty, S.; and Fox, T. 2001. Process models as tools in forestry research and management. Forest Science. 47(1): 2-8.

Landsberg, J.J.; Johnsen, K.H.; Albaugh, T.J., Allen, H.L.; McKeand, S.E. 2001. Applying 3-PG, a simple process-based model designated to produce practical results, to data from loblolly pine experiments. Forest Science. 47(1): 43-51.

Landsberg, J.J.; Waring, R.H. 1997. A generalized model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning. Forest Ecology and Management. 95: 209-228.

McMurtie, R.E.; Landsberg, J.J. 1992. Using a simulation model to evaluate the effects of water and nutrients on the growth and carbon partitioning of *Pinus radiata*. Forest Ecology and Management. 52: 243-260.

Sampson, D.A.; Johnsen, K.H.; Ludivici, K.H.; Albaugh, T.J.; Maier, C.A. 2001. Stand-scale correspondence in empirical and simulated labile carbohydrates in loblolly pine. Forest Science. 47(1): 2-8.

Teskey, R.O.; Bongarten, B.C.; Cregg, B.M.; Dougherty, P.M.; Hennessey, T.C. 1987. Physiology and genetics of tree growth response to moisture and temperature stress: an examination of the characteristics of loblolly pine (*Pinus taeda* L.). Tree Physiology. 3: 41-61.

Teskey, R.O.; Gholz, H.L.; Cropper, W.P. Jr. 1994. Influence of climate and fertilization on net photosynthesis of mature slash pine. Tree Physiology. 14: 1215-1227.

Vose, J.M.; Allen, H.L. 1988. Leaf area, stemwood growth and nutritional relationship in loblolly pine. Forest Science. 34: 547-563.

FAMILY DIFFERENCES IN ABOVEGROUND BIOMASS ALLOCATION IN LOBLOLLY PINE

Scott D. Roberts[1]

Abstract — The proportion of tree growth allocated to stemwood is an important economic component of growth efficiency. Differences in growth efficiency between species, or between families within species, may therefore be related to how growth is proportionally allocated between the stem and other aboveground biomass components. This study examines genetically related differences in aboveground biomass allocation in loblolly pine. I destructively sampled 58 trees from seven families selected to represent differences in growth rate (fast vs. slow) and crown size(large vs. small). The 15-year-old trees were all planted on the same site at the same spacing. Relative allocation to stem, foliage, and branch wood, and the ratio of foliage biomass to total crown biomass, were examined as a function of the logarithm of DBH. Large-crowned trees, compared to small-crowned trees of similar DBH, differed significantly in percent of total aboveground biomass allocated to the stem and to branch wood. Small-crowned families generally allocated proportionally less biomass to branch wood and more to the stem across the range of tree sizes examined. Relative allocation to foliage biomass did not differ, although lower allocation to branch biomass in small-crowned trees resulted in a significantly greater ratio of foliage to total crown biomass. Comparing trees from fast- and slow-growing families, only relative allocation to foliage differed significantly, although a strong interaction between DBH and growth characteristic made interpretation of the relationship difficult. These results suggest that families do differ in relative aboveground allocation, but these differences may not be related to family differences in stemwood productivity.

INTRODUCTION

A primary emphasis in silviculture is the management and control of tree growth. Total tree growth is a function of how much foliage is contained in the crown, the average photosynthetic rate of that foliage, and the efficiency in which the tree converts fixed carbohydrates into biomass. Of commercial importance is how much of that biomass, or growth, is converted to stemwood. Thus, how biomass is allocated within the tree plays an important role in forest productivity. Being able to manipulate growth allocation is one way that forest production can be improved. Allocation patterns in trees have been shown to vary with tree age, nutrient or water availability, and with stand density under which the tree develops.

Genetics also influence the proportion of growth allocated to useable portion of the plant, or harvest index (Dickmann 1985). Several analyses have suggested that genotypes promoting narrow, sparsely branched crowns lend themselves to greater growth efficiency (stem growth per unit leaf area)(Kärki and Tigerstedt 1985, Kuuluvainen 1988). However, studies specifically examining genetic differences in allocation patterns in trees, including examinations of southern pines, have had mixed results.

Seedling studies have often suggested genetic differences in allocation patterns. Li and others (1991), working with 1st-year seedlings of 23 loblolly pine families, found family differences in relative biomass allocation between root and shoot and between needles and stem. Bongarten and Teskey (1987) compared growth partitioning among 1-yr-old loblolly pine seedlings from seven seedlots of diverse geographic origin and found seedlot differences in relative allocation between root, stem, and foliage. However, these differences were not strongly related to differences in productivity. It is also not clear whether allocation differences observed in seedlings will be maintained in older stands.

Studies on older trees have been more equivocal, not always showing clear differences in allocation patterns. Pope (1979) examined 11-yr-old trees from four loblolly pine families, all selected for fast growth. The families differed in total production, but not in relative allocation patterns. Conversely, Matthews and others (1975) found family differences in the proportional distribution of woody biomass to the stems in 8-yr-old Virginia pine. Cannell and others (1983) reported that clones displaying sparse branching of both Sitka spruce and lodgepole pine were more efficient stemwood producers.

Commercial agriculture has exploited genetic differences in growth allocation to greatly increase crop yields. Forestry, however, while making some gains, has yet to take full advantage of these opportunities; and in fact has yet to establish a conclusive correlation between genetic differences in growth allocation and productivity. My objectives in this study were to determine if genetic differences in aboveground carbon partitioning could be observed in 15-year-old loblolly pine. If genetic differences were observed, I wanted to determine if these differences were related to family differences in productivity.

[1]Associate Professor, Department of Forestry, Mississippi State University, Mississippi State, MS 39762-9681

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Genetic characteristics and size distribution of 58 destructively sampled 15-year-old loblolly pine

Type				D. B. H.(cm)		Height (m)	
Family	n	Growth	Crown	Mean	Range	Mean	Range
NC1	8	Fast	Small	18.7	14.7-22.1	17.5	16.0-18.8
NC8	8	Fast	Small	19.8	15.8-23.5	17.2	15.4-18.5
NC4	9	Fast	Large	18.8	12.6-24.3	16.7	14.0-18.0
NC3	8	Slow	Small	19.2	12.4-23.3	16.4	13.8-18.0
NC6	8	Slow	Small	17.2	14.5-19.4	16.7	16.0-18.0
NC2	9	Slow	Large	20.1	15.8-25.3	16.2	14.4-17.5
NC5	8	Slow	Large	18.1	11.6-22.5	16.6	13.8-18.0
ALL	58			18.9	11.6-25.3	16.7	13.8-18.8

METHODS

This study was conducted on Mississippi State University's John Starr Memorial Forest located in Winston County, MS (33°16'N, 88°52W). The soils on this interior flatwood site are a Glossic Fragiudult (Prentiss loam) with a fragipan at a depth of approximately 0.5 to 0.8 m. Average annual temperature is ca. 17.2°, and average annual precipitation is ca. 1375 mm. Site index at base age 25 for loblolly pine is approximately 23 m.

Fifty-eight 15-year-old loblolly pine trees were destructively sampled in August 1999. The trees were open-pollinated progenies of seven North Carolina families selected from an industrial tree improvement program. Families were selected to represent combinations of fast vs. slow growth rate, and large vs. small crowns. The trees were all from a single block that had been planted in family rows on a 1.5m x 3.0m spacing. Trees ranged in size from 11.6 cm to 25.3 cm DBH (table 1). An eighth family and an unimproved check were excluded from this analysis because they were planted as border rows. A more complete description of the families is provided by Land and others (1991).

Height and DBH of each tree was measured before felling. After felling, each tree was separated into aboveground biomass components – stem (including bark), branches, and foliage with subtending twigs. Each component was weighed fresh in the field, and a subsample was weighed fresh and retained for further analysis. In the laboratory, subsamples were dried at 80°C to a constant weight and weighed to determine a fresh weight:dry weight ratio. Foliage was removed from twigs to determine a foliage weight:wood weight ratio. Using these ratios, a total dry weight for stemwood, branchwood, and foliage was determined for each tree.

Analysis to determine genetic differences in relative aboveground biomass allocation was based on the relationship between percent allocation to each biomass component and stem DBH. This accounted for the changes in biomass allocation that occur as trees get larger. Log-transformed values of DBH were used to account for the nonlinear nature of the relationships. Standard analysis of covariance procedures were employed to test for genetic differences, using the GLM procedure in SAS. Significance was accepted at a P-value $\leq$ 0.10.

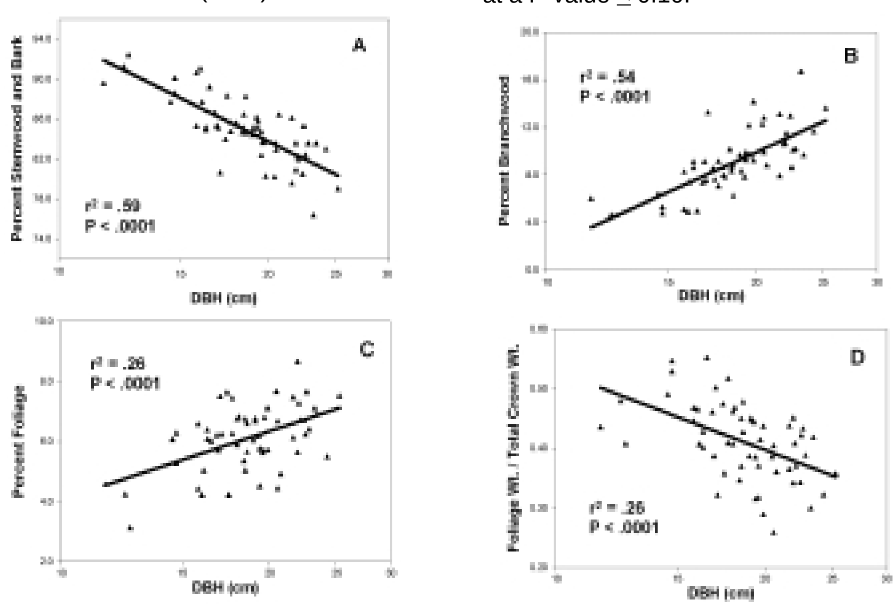


Figure 1 –- Log-linear relationships between stem DBH and percent of aboveground biomass allocated to (A) Stemwood and Bark, (B) Branchwood, and (C) Foliage. (D) shows the relationship between DBH and the ratio of foliage weight to total crown weight

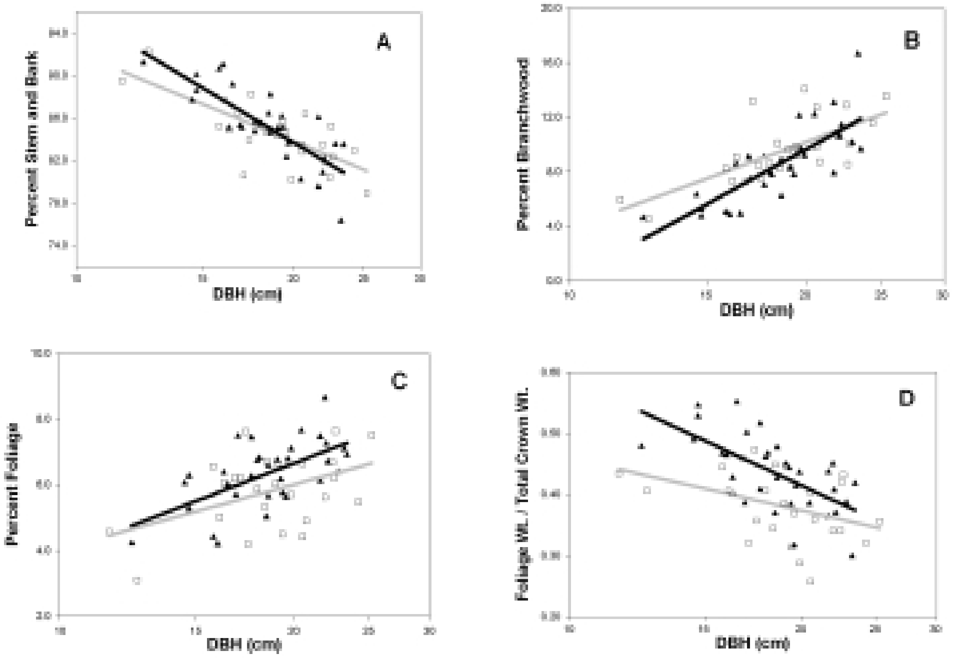


Figure 2 — Comparison of relative biomass allocation patterns between trees from small-crowned families (black triangles, black line) and trees from large-crowned families (gray squares, gray line). Differences in allocation to Stem (A) and Branchwood (B) are statistically significant. Differences in allocation to Foliage (C) are not significant. Differences in Foliage Ratio (D) are statistically significant.

RESULTS

The relationships between relative allocation to each of the biomass components and the logarithm of DBH across all 58 trees were all highly significant. Relative allocation to stemwood decreased as trees got larger (figure 1A), while allocation to both branches and foliage (figure 1B & 1C) increased with tree size. In addition, the ratio of foliage weight to total crown weight decreased as trees got larger (figure 1D). This foliage ratio has been used to help explain the decrease in leaf area efficiency (stem growth / LA) that has often been observed as mean crown size (leaf area per tree) increases (Roberts and Long 1992).

Reduced allocation to the stem and increased allocation to the crown as trees get larger is a common observation that illustrates the influence of normal developmental processes. Considerable variation exists in these relationships, however. Some of this variation might be explained by family differences in allocation patterns. However, when family was

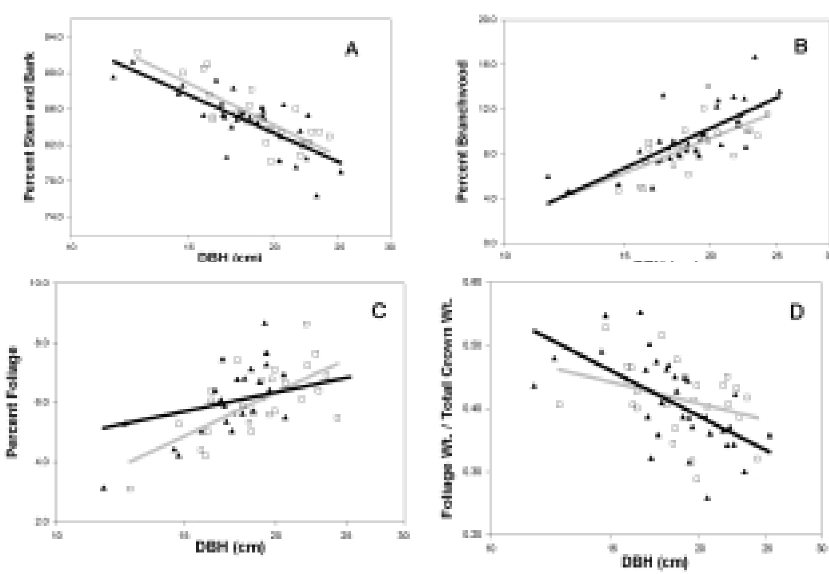


Figure 3 — Comparison of relative biomass allocation patterns between trees from fast growing families (gray squares, gray line) and trees from slow growing families (black triangles, black line). Differences in allocation to Stem (A) and Branchwood (B) are not statistically significant. Differences in allocation to Foliage (C) are statistically significant. Differences in Foliage Ratio (D) are not statistically significant.

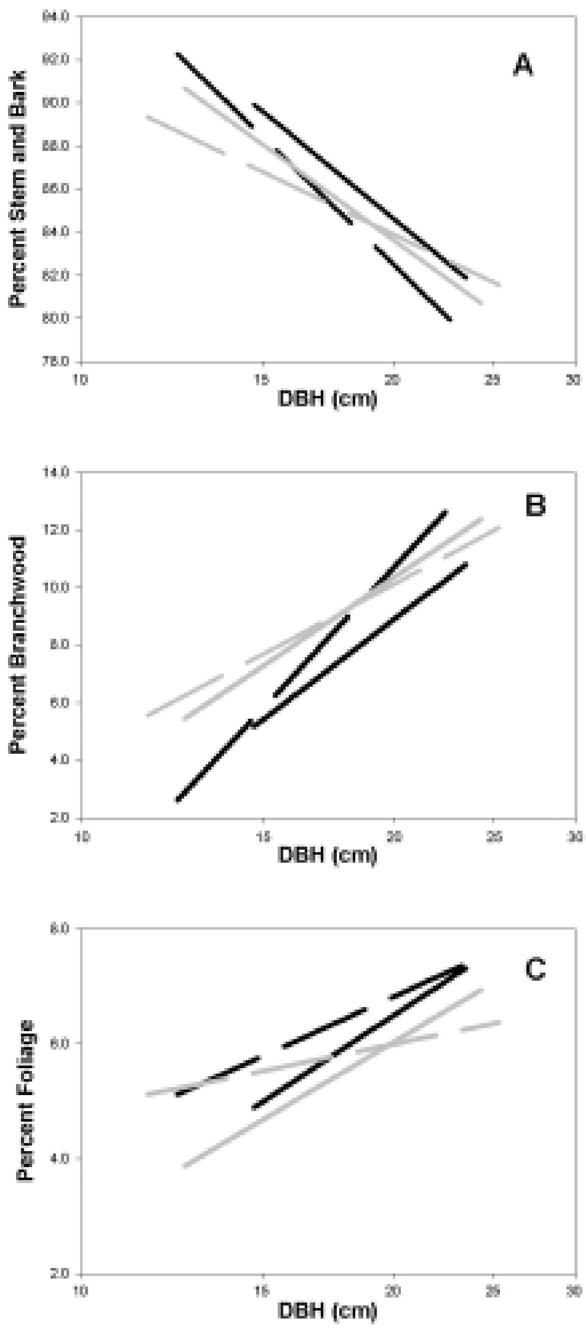


Figure 4 — Comparison of relative biomass allocation patterns between tree “types” representing combinations of crown size and growth rate. Solid black line = fast growing, small crown. Solid gray line = fast growing, large crown. Dashed black line = slow growing, small crown. Dashed gray line = slow growing, large crown. Type is statistically significant in explaining percent allocation to Stem (A). Differences in allocation to Branchwood (B) and to Foliage (C) are not statistically significant.

included as a covariate in the analysis, it was not significant suggesting that the variability in these relationships could not be explained by individual families.

The trees were separated into two groups of families that had been selected for differences in crown size, and the allocation relationships between these two groups were compared. Relative allocation to the stem differed significantly between the two groups. The slope adjusted mean percent allocation to stemwood was greater for small crowned families than for large crowned families (P = .08)(figure 2A), although there was a significant interaction (P = .08) between growth rate and log DBH.

Relative allocation to branchwood also differed significantly between the two groups. As might be expected, allocation to branches was greater for large crowned families than for small crowned families(P = .08)(figure 2B). The interaction term was again significant (P = .10), although when plotted on non-transformed axes, the curves appear to be coming together at higher DBH. This might indicate that the differences in allocation to branches are becoming less as the trees get larger.

Relative allocation to foliage was not significantly different between large and small crowned families (P = .53); although mean allocation to foliage was slightly higher for small crowned families (figure 2C). Due to differences in relative allocation to branches, foliage ratio did differ significantly between the two groups (P = .07). Families selected for small crowns had a higher ratio of foliage to total crown weight (figure 2D). Again, this could be an indication of greater leaf area efficiency for small crowned families.

The trees were next separated into two groups of families based on differences in inherent growth rate, and the allocation patterns of families selected for fast growth rate were compared to those selected for relatively slower growth rates. Relative allocation to the stem was not significantly different between the two groups (P = .62), although on average, fast growing families allocated slightly more to stem (figure 3A). Relative allocation to branches was also not significant (P = .66), but again, on average, fast growing families put slightly less into branches (figure 3B). There was a significant difference in the slope adjusted mean for relative allocation to foliage (P = .06), although, somewhat counter intuitively, slow growing families appear to allocate slightly more to foliage (fiigure 3C). However, a significant interaction between the growth term and *log* DBH (P = .06) made this difficult to interpret. Foliage ratio was not significantly different between the groups of fast growing versus slow growing families (figure 3D).

The families were lastly grouped based on combinations of crown size (large vs. small) and growth rate (fast vs. slow), and allocation patterns were compared between the four genetic “types.” Type was statistically significant in explaining variation in relative allocation to stem (P = .09), however, the significant interaction (P = .09) makes it difficult to separate the various types in any meaningful way. It is interesting to note, however, that the fast growing/small crowned families generally allocated proportionally more biomass to the stem than the other types (figure 4A) across the range of trees examined.

Genetic type had a P-value of .11 in explaining relative branch allocation, with a P-value of .12 for the interaction between type and dbh. Again, the fast growing/small crowned families separated themselves somewhat from the other types, allocating relatively less biomass to branchwood (figure 4B). Type was not significant in explaining allocation to foliage ($P = .30$), although relative allocation to foliage was again slightly lower for fast/large compared to fast/small (figure 4C).

DISCUSSION

This study is somewhat unique in that the genetic selections included not just families that differed in growth rate, but also families that presumably had inherent differences in allocation patterns, i.e., large vs. small crowns. As expected, there were differences in patterns of biomass partitioning related to selected differences in crown size. For a given tree dbh, families selected for small crowns allocated slightly more to the stem and slightly less to branches. Also, while not statistically significant, small crown families on average allocated slightly more to foliage. Small crowned families also tended to have significantly higher foliage ratios, which could be an indirect indicator of greater leaf area efficiency for small crowned trees. Comparisons among families selected for differences in growth rate showed only relative allocation to foliage differed significantly; and even then, the strong interaction makes interpretation difficult.

This study was limited in the range of tree sizes sampled; although to a certain extent that was a positive in this study. All of the trees developed on the same site, at the same spacing, and under essentially the same competitive environment, thus minimizing some of the developmentally influenced differences in growth allocation.

The results from this study provide support that there are genetic differences in aboveground allocation patterns in loblolly pine. This showed up primarily as differences in allocation between the stem and branches. The data do not statistically support the contention that faster growing families preferentially allocate more of their aboveground growth to the stem and less to the crown. However, while not statistically significant, mean values do suggest the possibility of greater relative allocation to stem in fast growing trees.

The results of this analysis agree with the conclusion of Bongarten and Teskey (1987) that genetic differences in dry matter partitioning do exist in loblolly pine, but that these differences are likely only partially responsible for observed differences in productivity. Other physiological and structural differences between families are sure to have major influences on growth and growth efficiency.

ACKNOWLEDGMENTS

Approved for publication as Journal Article No. FO-170 of the Forest and Wildlife Research Center, Mississippi State University.

REFERENCES

Bongarten, B.C.; Teskey, R.O. 1987. Dry weight partitioning and its relationship to productivity in loblolly pine seedlings from seven sources. Forest Science. 33(2): 255-267.

Cannell, M.G.R.; Sheppard, L.J.; Ford, E.D.; Wilson, R.H.F. 1983. Clonal differences in dry matter distribution, wood specific gravity and foliage "efficiency" in *Picea sitchensis* and *Pinus contorta*. Silvae Genetica. 32(5-6): 195-202.

Dickmann, D.I. 1985. The ideotype concept applied to forest trees. In: Cannell, M.G.R.; Jackson, J.E. Attributes of trees as crop plants. Huntington, U.K: Institute Of Terrestrial Ecology: 89-101.

Kärki, L.; Tigerstedt, P.M.A. 1985. Definition and exploitation of forest tree ideotypes in Finland. In: Cannell, M.G.R.; Jackson, J.E. Attributes of trees as crop plants. Huntington, U.K: Institute Of Terrestrial Ecology, Huntington, U.K: 102-109.

Kuuluvainen, T. 1988. Crown architecture and stemwood production in Norway spruce (*Picea abies*(L.)Karst.). Tree Physiology. 4: 337-346.

Land, S.B., Jr.; S.B.; Belli, K.L.; Duzan, H.W., Jr. 1991. Family, spacing, and family-by-spacing effects on loblolly pine during five years after planting. In: Coleman, S.S.; Neary, D.G. (comp). Proc. 6th Biennial South. Silv. Res. Conf. Gen. Tech. Rep. SE-70. U.S. Department of Agriculture, Forest Service: 744-756.

Li, B.; Allen, H.L.; McKeand, S.E. 1991. Nitrogen and family effects on biomass allocation of loblolly pine seedlings. Forest Science. 37(1): 271-283.

Matthews, J.A.; Feret, P.P.; Madgwick, H.A.I.; Bramlett, D.L. 1975. Genetic control of dry matter distribution in twenty half-sib families of Virginia pine. In: Proceedings 13th Southern Forest Tree Improvment Conference: 234-241.

Pope, P.E. 1979. The effect of genotype on biomass and nutrient content in 11-year-old loblolly pine plantations. Canadian Jounral of Forest Research. 9: 224-230.

Roberts, S.D.; Long, J.N. 1992. Production efficiency of *Abies lasiocarpa*: influence of vertical distribution of leaf area. Canadian. Journal of Forest Research. 22:1230-1234.

LAI-2000 ACCURACY, PRECISION, AND APPLICATION TO VISUAL ESTIMATION OF LEAF AREA INDEX OF LOBLOLLY PINE

Jason A. Gatch, Timothy B. Harrington, and James P. Castleberry[1]

Abstract—Leaf area index (LAI) is an important parameter of forest stand productivity that has been used to diagnose stand vigor and potential fertilizer response of southern pines. The LAI-2000 was tested for its ability to provide accurate and precise estimates of LAI of loblolly pine (Pinus taeda L.). To test instrument accuracy, regression was used to compare needefall estimates of LAI to those from the LAI-2000. To test instrument precision, analysis of variance was used to test sources of variation including instrument drift, overcast versus clear skies, time of day, and synchronization of above- and below-canopy sensors. A regression model was developed to calibrate visual estimates of LAI with LAI-2000 estimates and measures of height and stand basal area.

INTRODUCTION

Leaf area index (LAI) is the ratio of foliage surface area to ground surface area of a vegetative stand. It has become widely accepted as an indicator of photosynthetic capacity and level of stress of forest stands (Waring 1983). Since maximum LAI of a forest stand is limited by nutrient availability, any deviation from this value can indicate whether it will respond to fertilization, given fixed levels of other growth limiting factors, such as soil water and temperature (Vose and Allen, 1988). Thus, monitoring of LAI has potential application in prescribing of fertilizer treatments.

Techniques for estimating LAI of loblolly pine include those that utilize optical sensors, such as the LAI-2000 canopy analyzer (Li-Cor, Inc., Lincoln NB) and those that are conducted visually (Sampson and others 1996). Estimates from optical sensors are considered reasonably precise and accurate, but they require purchase of expensive equipment. Visual estimates can be reliable and inexpensive, given adequate training of observers, but they can suffer from bias. A combination of the two methods of LAI estimation may provide the desired level of accuracy, precision, and cost. This study had two objectives: 1) to quantify accuracy and precision of the LAI-2000, and 2) to calibrate visual estimates of LAI with LAI-2000 estimates and measures of height and stand basal area.

METHODS

The research was conducted in mid-rotation plantations of loblolly pine that were absent of shrubs and hardwoods. For each test of the LAI-2000, an above-canopy sensor (A) logged readings in a nearby large opening (no vegetation at greater than 15 degrees above the horizon) while a below-canopy sensor (B) was used to log readings within the study area. All LAI-2000 readings were taken with the sensor facing north at 1.4 meters above ground and a 90-degree view cap attached to the lens. In the laboratory, data from the two sensors were merged and LAI was calculated with Li-Cor software.

To test LAI-2000 accuracy, needlefall estimates of LAI were regressed against LAI-2000 estimates using measurements taken at a site near Eatonton GA (Scott 1997). Instrument precision was tested at sites near Athens GA or Phenix City AL by taking repeated measurements above the same points but under different instrument or sky conditions. These tests included comparisons of instrument drift (measurements taken in rapid progression), consecutive days with overcast versus clear skies, time of day (10:30, 11:30, or 12:30 Eastern Standard Time, EST), and levels of synchronization between A and B sensors to identical light conditions (1 percent, 5 percent, and 10 percent differences). Tests of instrument drift, time of day, and A/B sensor synchronization were repeated in March, June, and December 2000. Data from each precision test were subjected to analysis of variance with repeated measurements in time (split-plot design). A blocking factor of either individual sample points within a plot (drift study) or individual plots (time of day and synchronization studies) was included in the design. Linear regression was used to test the relationship between LAI estimates of overcast versus clear skies.

To address the second study objective, a total of 25 points were located in stands that varied in height and stand basal area. Following a period of field training, six observers estimated LAI visually above each point during early May and August 1999 using the methods of Sampson and others (1996). Approximately ten days prior to the visual estimates, LAI of each plot had been estimated with the LAI-2000. Measurements of average height and stand basal area also were taken in each plot. LAI-2000 estimates were regressed against visually estimated values, indicator variables for each observer, and stand variables. Stepwise regression with backward elimination was used to test the significance of each variable in the model.

[1]Research Coordinator and Associate Professor, School of Forest Resources, University of Georgia, Athens GA; Forest Biometrician, Mead Corporation, Phenix City, AL , respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

RESULTS

Accuracy of the LAI-2000 was high, with estimates exceeding those obtained from needlefall by only 4 percent. No significant differences were found when LAI-2000 measurements were taken in rapid succession above the same points (instrument drift). LAI-2000 readings taken on cloudy days averaged 7 percent greater than those taken on clear days. Readings taken at 10:30 EST averaged 4 percent greater than those taken at 11:30 and 12:30 EST. June readings with 1 percent synchronization between A and B sensors averaged 14 percent higher than those taken with 5 and 10 percent synchronizations; however, levels of synchronization did not affect readings taken in March and December.

For both the May and August data, a log-log regression model was found to be most suitable for calibrating visual estimates of LAI. In this model, the interaction of visually estimated LAI and stand basal area explained 55 to 68 percent of the variation in LAI-2000 estimates. Average height explained an additional 8 to 18 percent of variation. None of the indicator variables for individual observers were significant in the model, indicating an absence of bias.

CONCLUSIONS

Results of this research indicate that the LAI-2000 is a relatively accurate and precise instrument for estimating LAI of loblolly pine plantations. The instrument overestimated LAI slightly when compared to needlefall estimates. No significant drift was found in repeat measurements taken in rapid succession. On the average, the LAI-2000 gave somewhat higher readings under cloudy versus clear sky conditions. Readings were higher when taken during mid-morning versus late morning or early afternoon. Apparently bright sky conditions cause slight reductions in LAI-2000 estimates. Of all accuracy and precision tests, levels of synchronization between A and B sensors resulted in the greatest variation among readings. When synchronization between the two sensors was low (5 or 10 percent differences) during the June readings, LAI-2000 estimates were reduced in value relative to the 1-percent synchronization; however, this trend was not observed in the March and December readings. Thus, a high degree of synchronization (1- percent difference) is critical if the sensor is to detect change in LAI during the growing season.

The interaction of visually estimated LAI and stand basal area was the best single variable for predicting May or August LAI-2000 readings. This result suggests that visual estimates of LAI are influenced by stand basal area. In support of this finding, Sampson and others (1996) recommend a linear adjustment to visually estimated LAI to account for deviations in basal area from what would be considered full stocking. Average height, an indicator of age and site productivity, also was a significant variable in the regression models. The visual estimates of LAI were not influenced by potential bias from individual observers.

Our research has indicated that visual estimates of LAI can be successfully calibrated with more objective estimates obtained using needlefall collections or optical sensors. This combination of techniques can be used to provide a reliable and low cost method for estimating LAI of pine plantations.

ACKNOWLEDGMENTS

The authors are grateful to the Consortium for Accelerated Pine Production Studies (CAPPS), University of Georgia, and Mead Corporation for providing research sites. We also thank G. Munger and R.E. Will for providing estimates of specific leaf area.

REFERENCES

Sampson, D.A; H.L. Allen; E.M. Lunk; D.P. Blevins. 1996. The occular LAI comprarator® for loblolly pine, version 4.0. Forest Nutrition Cooperative, Department of Forestry, North Carolina State University, Raleigh, NC. 12p.

Scott, J.S. 1997. An examination of crown characteristics, growth efficiency, and bole wood maturation in loblolly pine of various stand densities grown in the absence of interspecific competition. M.S. thesis, University of Georgia. 54 p.

Vose, J.M. and H.L. Allen.1988. Leaf area, stemwood growth, and nutrition relationships in loblolly pine. Forest Science. 34: 546-563.

Waring, R.H. 1983. Estimating forest growth efficiency in relation to canopy leaf area. Advances in Ecological Research. 13: 327-354.

SEASONAL DYNAMICS IN LEAF AREA INDEX IN INTENSIVELY MANAGED LOBLOLLY PINE

Timothy B. Harrington, Jason A. Gatch, and Bruce E. Borders[1]

Abstract—Leaf area index (LAI; leaf area per ground area) was measured monthly or bi-monthly for two years (March 1999 to February 2001) with the LAI-2000 in intensively managed plantations of loblolly pine (Pinus taeda L.) at Eatonton and Waycross GA. Since establishment of the three age classes at each site, the stands have received combinations of complete weed control and annual fertilization. The youngest age class at Eatonton continued to accumulate LAI for the duration of the study, while LAI did not differ significantly among age classes at Waycross. Fertilization caused increases in LAI by as much as a full unit, except in the youngest age class at Eatonton. Seasonal development of LAI from associated hardwoods and shrubs was more evident for the deciduous community at Eatonton than for the evergreen community at Waycross. The LAI-2000 successfully detected differences in LAI due to seasonal change, stages of stand development, stand nutrition, and presence or absence of non-pine woody vegetation.

INTRODUCTION

Leaf area is the most important morphological feature affecting productivity of a forest stand because it is the primary site of energy and gas exchange for photosynthesis and respiration. Soon after crown closure, forest stands begin an asymptotic approach to their maximum LAI. Maximum LAI occurs at full stocking and it can vary with site quality and silvicultural inputs. Recent interest in the use of LAI as a management diagnostic for predicting stand productivity and potential for treatment response of loblolly pine has prompted the development of field estimation techniques (Sampson and others 1996). However, an incomplete understanding currently exists regarding how LAI varies seasonally, especially for stands managed with different silvicultural intensities. Previous research on LAI of loblolly pine has focused on peak growing season values derived from needlefall or branch samples (Vose and Allen 1988, Dalla-Tea and Jokela 1991, McCrady and Jokela 1996) and has not considered seasonal dynamics. Therefore, the objective of this research was to characterize seasonal dynamics of loblolly pine LAI as influenced by weed control and fertilization.

METHODS

The research was conducted at mechanically prepared sites in the Piedmont (Eatonton) and Lower Coastal Plain (Waycross) of Georgia. Four treatments were compared: 1) untreated check, 2) annual fertilization with nitrogen, plus first- and second-year applications of phosphorus and potassium, 3) complete weed control, and 4) the combination of annual fertilization and complete weed control. At each site loblolly pine was planted at a 2.4-meter square spacing in 0.15-hectare plots. Each treatment was replicated in two blocks per site. To study treatment effects over different time periods, the entire study was planted at each site during different years to provide three age classes: oldest (1987 and 1988 plantings for Waycross and Eatonton, respectively), middle (1989 and 1990 plantings) and youngest (1993 and 1995).

Monthly or bimonthly measurements of LAI were taken from March 1999 to February 2001 with the LAI-2000 canopy analyzer (Li-Cor, Inc., Lincoln NB). A total of twelve LAI readings were taken at the same randomly located points on each plot. An above-canopy sensor logged readings in a nearby large opening (no vegetation at greater than 15 degrees above the horizon) while a below-canopy sensor was used to log readings within the study area. All LAI-2000 readings were taken with the sensor facing north at 1.4 meters above ground and a 90-degree view cap attached to the lens. In the laboratory, data from the two sensors were merged and LAI was calculated with Li-Cor software. Data from each location were analyzed separately. Plot averages for each sample date were subjected to analysis of variance to test main effects (treatment and age class) and their interaction.

RESULTS

At Eatonton, LAI of the youngest age class continued to increase for the duration of the study, while LAI of the middle and oldest age classes had similar peak values during the 1999 and 2000 growing seasons. The interaction of weed control and age class was significant for most of the sample dates. In the youngest age class, LAI was greater in the presence versus absence of weed control because this treatment greatly accelerated the development and dominance of a pine canopy. Shrub and hardwood species contributed little to LAI in these five- to six-year-old stands.

[1]Associate Professor, Research Coordinator, and Professor, School of Forest Resources, University of Georgia, Athens GA, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

However, in the oldest age class, growing season LAI was greater in the absence versus presence of weed control because the addition of non-pine woody vegetation increased LAI by up to 30 percent. Fertilization was associated with significant increases in LAI by as much as a full unit, but these responses were limited primarily to the middle and oldest age classes.

At Waycross, there were no significant differences in LAI among age classes. In addition, the effects of weed control and fertilization were additive and did not interact significantly with age class. Weed control was associated with a reduction in LAI because of the resulting absence of non-pine woody vegetation. Fertilization was associated with increases in LAI by as much as a full unit.

At each site, increases in LAI from fertilization were sustained throughout the growing and dormant seasons. This indicates that the pine canopy is maintaining a larger surface area of needles throughout the year, and not just during periods of active shoot growth.

Development of LAI in the absence of weed control differed strongly between the two sites. At Eatonton, LAI of the deciduous hardwood and shrub community climbed rapidly in the spring and declined rapidly in the fall. At Waycross, the seasonal change in LAI resulting from associated hardwoods and shrubs was less conspicuous, probably because many of the species are evergreen, such as gallberry (*Ilex glabra* L.) and wax myrtle (*Myrica cerifera* L.).

CONCLUSIONS

LAI development of the youngest age class at Eatonton lagged behind that of Waycross. Likewise, LAI responses to fertilization were not yet detectable in the youngest age class at Eatonton. In contrast, peak LAI values and responses to fertilization and weed control differed little among age classes at Waycross. Thus, stands of the youngest age class at Eatonton continued to accumulate leaf area, while those at Waycross had already reached stable values. Differences in LAI due to stand nutrition were maintained throughout the year, and not just during periods of active shoot growth.

The LAI-2000 was able to detect differences in LAI of loblolly pine plantations attributable to seasonal change, age class, stand nutrition, and presence or absence of non-pine woody vegetation. Subtle differences in seasonal rates of LAI development between deciduous and evergreen hardwood and shrub communities also were evident.

ACKNOWLEDGMENTS

The authors are grateful to the Consortium for Accelerated Pine Production Studies (CAPPS), University of Georgia, for assisting with maintenance of the study sites. Partial funding for travel was provided by the U.S. Department of Energy under Cooperative Agreement DE-FC36-98GO10363.

REFERENCES

Dalla-Tea, F.; E.J. Jokela. 1991. Needlefall, canopy light interception, and productivity of young, intensively managed slash and loblolly pine stands. Forest Science. 37: 1298-1313.

McCrady, R.L.; E.J. Jokela. 1996. Growth phenology and crown structure of selected loblolly pine families planted at two spacings. Forest Science. 42: 46-57.

Sampson, D.A.; H.L. Allen; E.M. Lunk; D.P. Blevins. 1996. The ocular LAI comparator© for loblolly pine, version 4.0. Raleigh NC: Forest Nutrition Cooperative, Department of Forestry, North Carolina State University: 12 p.

Vose, J.M. and H.L. Allen. 1988. Leaf area, stemwood growth, and nutrition relationships in loblolly pine. Forest Science. 34: 546-563.

COMPARISON OF GROWTH EFFICIENCY OF MATURE LONGLEAF AND SLASH PINE TREES

Steven B. Jack, Mary Carol P. Sheffield, and Daniel J. McConville[1]

Abstract—Variation in aboveground biomass partitioning (between the stem, branches, and foliage) of mature trees is a key determinant of growth potential. Investment of photosynthate in crown components generally results in greater overall biomass production of longer duration. The increased production of crown components may be an investment in longterm aboveground production and can result in increased growth efficiency (defined as biomass increment per unit leaf area). This study was initiated to compare the relationships of crown structure to aboveground allocation and stemwood growth for mature planted slash pine (*Pinus elliottii* Engelm.) and naturally regenerated longleaf pine (*P. palustris* Mill.) trees. Total tree height, diameter at breast height, height to base of the live crown, and bark thickness were measured and increment cores taken from longleaf and slash pine trees of similar ages growing on similar sites. These data were used with allometric equations, developed previously for each species from destructive sampling procedures at these sites, to predict projected leaf area and 5-year stem biomass production. Growth efficiency for trees was calculated as 5-year stemwood biomass increment per unit projected leaf area. Average (per tree) stem biomass production was not statistically different between longleaf pine and slash pine, nor were average projected leaf areas. Average growth efficiency of longleaf pine was significantly greater than that of slash pine (P < 0.10); graphical examination of individual tree data, however, did not indicate strong or significant differences in growth efficiency between species when comparing trees of equal size. These findings suggest that greater investment in crown structural components by longleaf pine may, at the stand-level, help to maintain stemwood production over a longer lifespan relative to slash pine, but individual tree results are less clear.

INTRODUCTION

Crown structure, characterized by the size (biomass or surface area) and distribution of individual crown elements (i.e., branches, shoots, and foliage), is a key variable in forest ecological studies. Crown structure is functionally related to tree growth through its inherent relation to radiation interception and gas exchange (Jarvis and Leverenz 1983, Stenberg and others 1994, Teskey and others 1994). It also strongly affects sub-canopy plant diversity by modifying light quantity and quality, thereby affecting understory species composition (Kimmins 1997).

Biomass and surface area equations have been used to determine dry weight allocation patterns, which in turn have been related to productivity. Research has shown that dry matter allocation to foliage, branches, and stemwood is variable and affected by several factors including tree age, species, and climatic conditions (Gholz and Cropper 1991, Gower and others 1994, Teskey and others 1994). Many, and perhaps most, of these studies, however, have investigated the effects of these factors on dry weight partitioning in young trees, with far fewer studies looking at allocation patterns in mature trees. For example, little is known about how mature trees allocate carbon or how the relationship between crown structure and stemwood growth varies with age for different tree species.

One species comparison of interest is that between longleaf pine (*Pinus palustris* Mill.) and slash pine (*P. elliottii* Engelm.) because of the large overlap in their habitat distributions and because they are often found growing on the same sites. It is generally accepted that slash pine grows more quickly (and probably with greater efficiency) at young ages, but longleaf pine produces more cumulative growth at older ages and over longer time periods (Boyer 1990, Lohrey and Kossuth 1990); i.e., growth rates decline in slash pine at ages greater than 25-30 years whereas longleaf pine growth rates are maintained or may increase for many more years. This presumption has not been rigorously tested for older trees, however, largely due to the lack of older slash pine stands and few comparable stands of longleaf and slash pine growing on similar soils. An additional factor is that slash pine is shorter-lived, generally not exceeding 100-200 years in age (Hebb and Clewell 1976), whereas longleaf pine can live to be as old as 500 years (Landers and others 1995). Thus, the same chronological ages may represent different physiological ages for the two species.

[1]Conservation Ecologist and former Research Technician, J.W. Jones Ecological Research Center, Rt 2 Box 2324, Newton, GA 31770; Field and Data Coordinator, Cooperative Forestry Research Unit, University of Maine, 5755 Nutting Hall, Rm. 227, Orono, ME 04469-5755, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Average stand structural characteristics for the sampled longleaf and slash pine stands

	Longleaf pine	Slash pine
Density (trees/ha)	135	107
DBH (cm)	37.4	41.7
Height (m)	24.1	27.2
Basal area (m^2/ha)	13.3	14.8

In an earlier, unpublished biomass comparison study of longleaf pine and slash pine, we developed allometric equations for predicting stem biomass production and projected leaf area for both species at these sites. That study indicated that mature (60-75 year old) planted slash pine and naturally regenerated longleaf pine exhibited strong differences in aboveground allocation between foliage, branches, and stemwood. The objective of this study was to use the allometric equations developed in the previous study in conjunction with recent growth measurements to examine how patterns of allocation affect growth efficiency in mature longleaf pine and slash pine stands growing on similar sites.

METHODS

Site Descriptions

This study was conducted at the Joseph W. Jones Ecological Research Center located in Baker County, Georgia (31° 13'N, 84° 29'W). Two specific sites were sampled: a 52 hectare stand dominated by naturally regenerated longleaf pine (average age of 73 years), and a 77 hectare slash pine stand planted in 1938. Both sites are located on well-drained upland and fluvial terraces, and the soils are Typic and Arenic Hapludults, with loamy sands over sandy loams to sandy clay loams. The soil moisture regime is similar at the two sites. The slash pine stand was thinned periodically and is relatively open, although a small component of younger, naturally occurring slash pine and *Quercus* species occupies the under- and mid-stories. The longleaf pine stand has also had some harvest entries, though less frequently than the slash pine, and contains multiple age classes of longleaf pine. The understory of the longleaf pine stand is dominated by grasses with some hardwoods maintained in a shrubby state through the use of frequent prescribed fire. Stand structural characteristics are summarized in table 1.

Biomass Sampling

Longleaf pine biomass was sampled in 1996 through the destructive sampling of 23 trees representing the range of tree diameters in the stand. Common biomass sampling techniques were employed, including the measurement of stem diameter and collection of disks at fixed points along the stem, measurement of all branch diameters and lengths, measurement of total green weight of the stem, branches and foliage in the field, and the collection of subsamples from each component to determine fresh weight:dry weight ratios. In addition, projected leaf area per unit dry weight of foliage was determined in the laboratory. Sixteen slash pine trees were sampled in 1998 using comparable field and laboratory methodologies. These data were used to develop allometric prediction equations for each species to predict individual tree stem, branch and foliage biomass and projected leaf area from easily measured parameters.

Growth Measurements and Calculations

Six 0.5 hectare plots were established for sampling biomass increment and growth efficiency, with 3 plots in each stand type (longleaf and slash pine). At each plot all trees greater than 15 centimeter dbh were sampled for a total of approximately 50-65 trees per plot. Total tree height, diameter at breast height, height to the base of the live crown, and bark thickness were measured. In addition, two increment cores were extracted at right angles from every tree and measured for 5-year radial increment.

Using these data and the previously developed allometric equations, aboveground biomass allocation and projected leaf area were predicted for each tree, and a 5-year stem biomass increment calculated using the radial increment measurements. Growth efficiency was calculated for each tree as the 5-year stem biomass increment divided by the projected leaf area.

Statistical Analyses

T-tests were conducted to determine if differences in stem biomass production, projected leaf area and overall growth efficiency existed between species, with statistical significance set at a = 0.10. Also, linear regressions were developed for the transformed individual tree data and the slopes of the relationships compared for the two species.

RESULTS

The average aboveground biomass allocation, as predicted from the allometric equations, differed considerably between species as shown in figure 1. Longleaf pine had more than double the percentage allocation to crown components in comparison to slash pine, and this same doubling effect also held true for the individual crown components (branches and foliage). In other words, for equal size trees, slash pine allocated significantly more biomass increment to the stem than did longleaf pine.

Table 2—Comparison of average per tree values calculated for projected leaf area, stem biomass increment and stem growth efficiency for longleaf and slash pine. Statistical comparisons were conducted using T-tests

	Longleaf Pine	Slash Pine	P>T
Projected leaf area (m^2)	100.5	93.2	0.14
Stem biomass increment(kg)	53.4	52.7	0.78
Growth efficiency (kg/m^2)	0.64	0.58	0.07

When comparing average tree-level values (table 2) we found that projected leaf area and 5-year stem biomass increment did not differ statistically between species. Average growth efficiency was significantly greater for longleaf pine (table 2), indicating that, on average, longleaf pine produced more stem biomass per unit of projected leaf area than slash pine. Yet when the individual tree data for stem increment and growth efficiency were plotted versus projected leaf area (figure 2), no clear species differences were apparent. Linear regressions of log-transformed data for growth efficiency as a function of projected leaf area produced significantly different slopes (results not shown). Given the relationship shown in figure 2, however, we did not think this result was biologically significant but instead was likely only the result of examining dissimilar ranges of data for the two species. Figure 3 indicates that the species do segregate based upon stand-influenced structural characteristics, as indicated by the index of modified crown ratio (defined as live crown length divided by (height - 1.3 meters)).

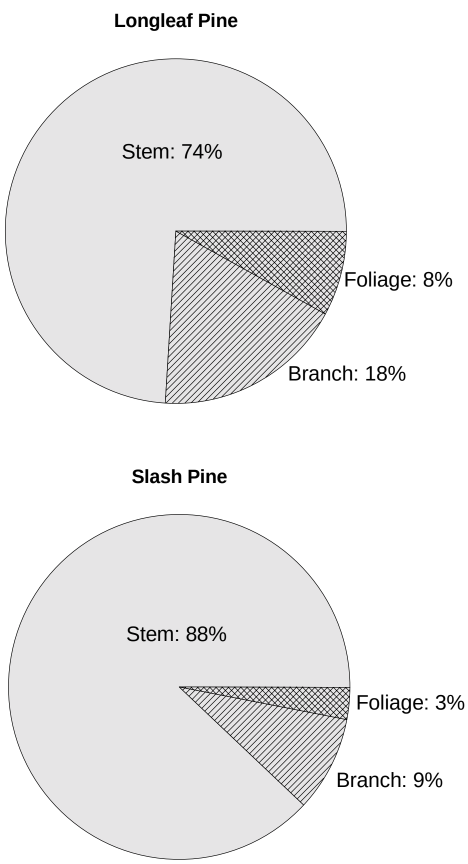


Figure 1—Average aboveground biomass distribution (by percent) for longleaf pine (top) and slash pine (bottom).

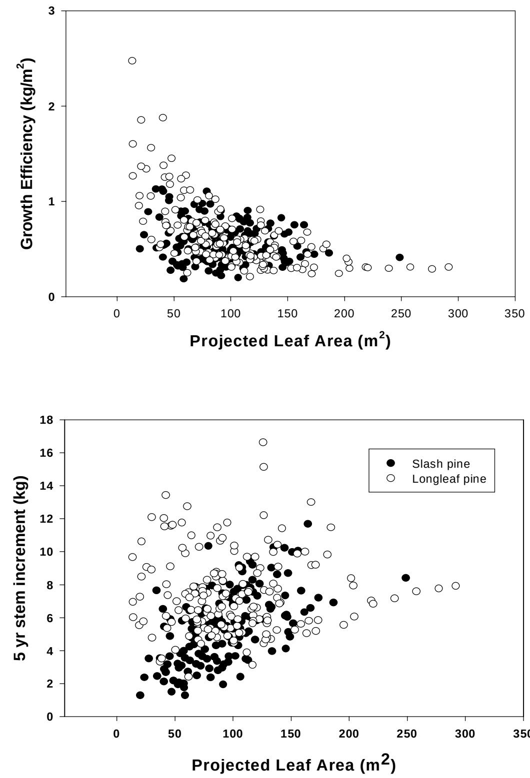


Figure 2—Relationship between 5-year stem biomass increment (top) and stem growth efficiency (bottom) and projected leaf area for all sampled trees.

DISCUSSION

Studies of resource allocation in other species suggest that stemwood accumulation relative to branches and foliage increases with age, stand density and site quality (Binkley 1983, Espinosa Bancalari and Perry 1987, Fogel and Hunt 1983, Keyes and Grier 1981, Turner and Long 1975). Younger or more open stands, or stands growing on poor sites, tend to have a relatively higher proportion of biomass in foliage and branches (e.g., Binkley 1983), whereas older or denser stands invest relatively less in crowns (e.g., Espinosa Bancalari and Perry 1987 for density).

It is clear from figure 1 that the two species, though of similar age and growing on comparable sites, allocate aboveground growth quite differently. This result was not surprising given the known differences in growth patterns and the visually distinct crown forms of the two species. What was surprising, however, is that these different patterns of allocation did not lead to significant differences in per tree projected leaf area or stem biomass increment for the 5-year period measured.

The lack of clear differences in stem increment between species was contrary to the results we expected given the ages of the trees in this study. Plantation grown 60-year-old slash pine are likely at a more advanced physiological age

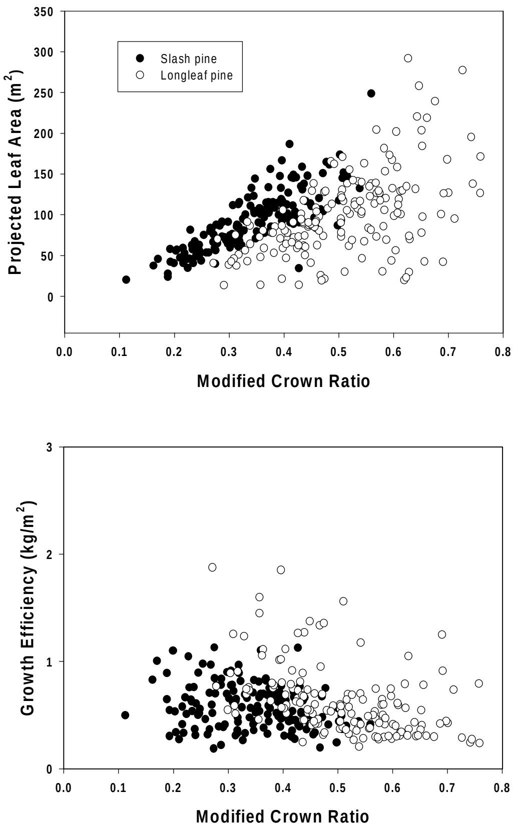


Figure 3—Influence of stand and tree structure, as indicated by a modified crown ratio (live crown length divided by (total tree height - 1.3)), on per tree projected leaf area (top) and stem growth efficiency (bottom).

than 73-year-old (on average) longleaf pine in a natural stand. We therefore expected that production in slash pine would have declined and the longleaf pine would, on average, have higher production. Past stand management must be taken into account, however. The slash pine stand was thinned for a research study subsequent to the biomass sampling but prior to the plot sampling for growth predictions. Thus, the slash pine results presented here are from the residual trees (not marked for removal) and represent the best growing individuals in the stand, as was documented in a companion study from the same area (McConville and others 1999). In this instance, then, we actually compared the "best" slash pine trees with randomly selected trees from the longleaf pine stand (i.e., not those selected for good growth). This fact could have an effect on the results presented.

The results for growth efficiency were also not quite as we expected a priori. Growth efficiency was higher on average for longleaf pine (table 2). But, upon examining results for individual trees (figure 2), any differences in the average values appear to be due to disparities in the range of data included in the sample rather than to true biological differences between the species. The form of the relationship between growth efficiency and leaf area found in figure 2 is typical of those found for other shade intolerant species where light is not a limiting factor (Roberts and others 1993). The negative exponential form of the relationship can be attributed to variation in structural characteristics of the canopy (Roberts and others 1993); figs. 1 and 3 indicate that there are some differences in canopy structure for the two species, and these differences may in part explain the observed small differences in growth efficiency between slash and longleaf pine.

The discussion so far has focused on results for individual trees. When comparing stem growth at the stand-level, however, the relatively small differences measured for individual trees may become more significant. That is, the longleaf pine stand had higher tree densities (table 1); thus, if these trees had the same or slightly higher average stem increment or growth efficiency, then the total, stand-level production of longleaf pine will be greater than for slash pine. It is important not to push this line of reasoning too far, however, because the results represent only a single case study.

CONCLUSIONS

Despite expectations, in this study the stem biomass increment and projected leaf area of mature longleaf and slash pine did not differ significantly even though there are clear differences in the allocation of aboveground biomass. Also, the statistical differences in average growth efficiency were not apparent when data from all individual trees were examined. The lack of clear differentiation between species is probably attributable to past stand history and management, but this factor should be investigated more closely through additional studies.

In short, individual trees of the two species with similar chronological ages and grown on comparable sites do not appear to produce greatly different stem biomass for a given tree size. There may, however, be some disparities in stand-level production, at least as indicated by the results of this one study. For longterm planning purposes an additional consideration is the known difference in longevity for the two species, which could affect how long each species can be expected to maintain adequate stand stocking over long rotations.

ACKNOWLEDGMENTS

We thank the J.W. Jones Ecological Research Center for funding this study, and R. Mitchell and S. Pecot of the Jones Center for access to the longleaf pine data.

REFERENCES

Binkley, D. 1983. Ecosystem production in Douglas-fir plantations: interaction of red alder and site fertility. Forest Ecology and Management. 5: 215-227.

Boyer, W.D. 1990. *Pinus palustris* Mill., Longleaf pine. In: Burns, R.M.; Honkala, B.H., technical coordinators. Silvics of North America, Vol. 1, Conifers. Agric. Handb. 654. U.S. Department of Agriculture, Forest Service: 405-412.

Espinosa Bancalara, M.A.; Perry, D.A.. 1987. Distribution and increment of biomass in adjacent young Douglas-fir stands with different early growth rates. Canadian Journal of Forest Research. 17: 722-730.

Fogel, R.; Hunt, G. 1983. Contribution of mycorrhizae soil fungi to nutrient cycling in a Douglas-fir ecosystem. Canadian Journal of Forest Research. 13: 219-232.

Gholz, H. L.; Cropper, Jr., W. P. 1991. Carbohydrate dynamics in mature *Pinus elliottii* var. *elliottii* trees. Canadian Journal of Forest Research. 21:1742-1747.

Gower, S.T.; Gholz, H.L.; Nakane, K.; Baldwin, V.C. 1994. Production and carbon allocation patterns in pine forests. Ecological Bulletin. 43:115-135.

Hebb, E.A.; Clewell, A.F. 1976. A remnant stand of old-growth slash pine in the Florida panhandle. Bulletin of the Torrey Botanical Club. 103:1-9.

Jarvis, P. G.; Leverenz, J. W. 1983. Productivity of temperate, deciduous and evergreen forests. In: Lange, O.L.; Noble, P.S.; Osmond, C.N.; Ziegler, H., eds. Encyclopedia of Plant Ecology IV. Springer-Verlag. Berlin: 234-280.

Keyes, M.R.; Grier, C.C. 1981. Above- and below-ground net production in 40-year old Douglas-fir stands on low and high production sites. Canadian Journal of Forest Research. 11: 599-605.

Kimmins, J.P. 1997. Forest Ecology, 2d ed. Upper Saddle River, NJ: Prentice-Hall, Inc.

Landers, J.L.; Van Lear, D.H.; Boyer, W.D. 1995. The longleaf pine forests of the southeast: requiem or renaissance? Journal of Forestry. 93: 39-44.

Lohrey, R.E.; Kossuth, S.V. 1990. *Pinus elliottii* Engelm., Slash pine. IN Burns, R.M.; Honkala, B.H., technical coordinators. Silvics of North America, Vol. 1, Conifers. Agric. Handb. 654.U.S. Department of Agriculture Forest Service: 338-347.

McConville, D.J.; Jack, S.B.; Mitchell, R.J. 1999. A quantitative assessment of slash pine crown structure in trees marked for gap creation. In: Haywood, J.D., editor. Proceedings of the Tenth Biennial Southern Silvicultural Research Conference. USDA Forest Service General Technical Report SRS-30: 539-541.

Roberts, S.D.; Long, J.N.; Smith, F.W. 1993. Canopy stratification and leaf area efficiency: a conceptualization. Forest Ecology and Management. 60: 143-156.

Stenberg, P.; Kuuluvainen, T.; Kellomaki, S.; Grace, J.C.; Jokela, E.J.; Gholz, H. L. 1994. Crown structure, light interception and productivity of pine trees and stands. Ecological Bulletin. 43: 20-34.

Teskey, R. O.; Whitehead, D.; Linder, S. 1994. Photosynthesis and carbon gain by pines. Ecological Bulletin. 43: 35-49.

Turner, J.; Long, J.N. 1975. Accumulation of organic matter in a series of Douglas-fir stands. Canadian Journal of Forest Research. 5: 681-690.

PHOTOSYNTHETIC LIGHT RESPONSE OF BOTTOMLAND OAK SEEDLINGS RAISED UNDER PARTIAL SUNLIGHT

Emile S. Gardiner[1]

Abstract—Seedlings of cherrybark oak (*Quercus pagoda* Rafinesque), Nuttall oak (*Quercus nuttallii* Palmer) and overcup oak (*Quercus lyrata* Walter) were grown under two light levels, partial (20 percent) or full sunlight, to study physiological acclimation of leaves to low light availability. Shifts in leaf morphology were noted for seedlings raised beneath partial sunlight, and photosynthetic light response curves indicated that bottomland oaks varied in their degree of physiological acclimation to low light availability. Greatest shifts in leaf function under partial sunlight were observed for cherrybark oak which exhibited a 48 percent decrease in net photosynthesis at light saturation ($P_{n\text{-}sat}$), and a 55 percent decrease in dark respiration rate (R_d) (based on leaf area). These adjustments to the photosynthetic mechanism were accompanied by a 46 percent decrease in the light compensation point (LCP). In contrast, Nuttall oak leaves showed similar rates of $P_{n\text{-}sat}$, R_d and apparent quantum yield (φ) regardless of the light environment in which they developed. Overcup oak leaves were intermediate in response exhibiting a 53 percent decreased in R_d and a 57 percent increase in φ, but $P_{n\text{-}sat}$ was not decreased for leaves grown under partial sunlight. Silvicultural implications of these results for bottomland oak regeneration are presented.

INTRODUCTION

Bottomland hardwood forests of the southern United States characteristically support a rich diversity of tree species. Of the more than 70 tree species endemic to major and minor river bottoms, bottomland oaks are often primary components of many species-site associations (Putnam and others 1960). Though bottomland oaks are often a primary component of mixed species, bottomland hardwood stands, regeneration of these desired species can be problematic. The problem of obtaining an adequate stocking of vigorous oak (*Quercus* spp.) reproduction following regeneration harvests in southern bottomlands has been addressed by numerous authors for several decades (Chambers and others 1987, Hodges and Janzen 1987, Johnson 1975, Nix and others 1985). Yet, reliable techniques for securing oak regeneration in bottomlands are still unavailable. A stronger understanding of how environmental factors regulate oak seedling establishment and growth is clearly needed to develop silvicultural practices that foster oak regeneration (Hodges and Gardiner 1993).

Previous research in bottomlands has identified several environmental factors that potentially contribute to oak regeneration problems. For example, flooding is a prominent factor in bottomlands that can limit establishment or destroy entire cohorts of oak reproduction (Johnson and Deen 1993, Young and others 1995). Competition from other tree or vine species can be severe in bottomlands, particularly on well drained, productive sites (Gardiner and Yeiser 1999, Johnson 1975). Mast depredation may limit seed tree fecundity, and herbivory often reduces vigor of established seedlings (Johnson 1981, Lockhart and others 2000).

Though many factors potentially contribute to poorly stocked oak regeneration pools in bottomlands, some problems are likely linked to light availability. This may be realized through the observations that oak seedlings are generally intolerant of shade, and light availability in the understory of mature bottomland hardwood forests is generally low (Hodges and Gardiner 1993, Jenkins and Chambers 1989). Recent research has established the importance of sufficient light availability to development of vigorous cherrybark oak (*Quercus pagoda* Rafinesque) reproduction (Gardiner and Hodges 1998). And, silvicultural practices which increase understory light availability can be applied to improve size and vigor of cherrybark oak reproduction (Lockhart and others 2000). Though these findings are promising, much remains to be learned about the basic functioning of oak seedlings relative to their light environment. This experiment was initiated to study the effects of light availability on the photosynthetic light response of seedlings of three bottomland oak species. Additionally, leaf morphology was examined to describe potential changes in functional processes relative to structural acclimation.

METHODS

The experiment was conducted during the 1993 growing season at the Mississippi State University, Blackjack Research Farm located near Starkville, MS (33° 26' N Latitude, 88° 46' W Longitude). Twenty-four, 1-year-old dormant seedlings of cherrybark oak, Nuttall oak (*Quercus nuttallii* Palmer) and overcup oak (*Quercus lyrata* Walter) (72 total seedlings) were transplanted into 18.9-liter pots filled with potting soil and sand (50:50, volume:volume). Pots were fertilized with a 14-14-14 (nitrogen-phosphorous-potassium) time release, granule (Osmocote,

[1]Research Forester, Center for Bottomland Hardwoods Research, Southern Research Station, USDA Forest Service, Stoneville, MS.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Grace-Sierra Horticultural Products company, Milpitas, CA), and watered as needed to maintain ample soil moisture. Half of the seedlings were randomly selected and placed in a shade house (20 percent of full sunlight), while the other half were grown under full sunlight in an adjacent field.

Measurements of leaf morphology and physiology began in July after maturation of the second flush of shoot growth. Leaf morphology was characterized through measurements of blade area and leaf mass per area. Measurements were collected on 30 randomly selected leaves for each species and light environment (5 randomly selected leaves from 6 randomly selected seedlings). Blade area (centimeter^2) was measured with a digital image analysis system (Decagon Devices Inc, Pullman, WA, USA). Leaves were oven-dried for 48 hours at 70° Celsius, then leaf mass per area was calculated as blade mass ÷ blade area (milligrams centimeter^{-2}).

Leaf physiology was characterized by measuring the photosynthetic light response of four randomly selected seedlings for each species and light environment. Seedlings were brought into the laboratory where measurements were conducted on a single, fully developed leaf from the terminal flush. Net photosynthesis (P_n) (micromoles centimeter^{-2} second^{-1}) of each sample leaf was recorded at 6 levels of photosynthetic photon flux density (PPFD) (0, 25, 100, 400, 800, 1600 micromoles meter^{-2} second^{-1}) with a LCA-3 gas analyzer and Parkinson leaf cuvette (The Analytical Development Company Ltd, England). P_n measurements on each sample leaf began at the lowest light level and ended with the highest light level. Particular light levels were produced by filtering light from a 300 watt quartz filament bulb with various configurations of neutral density filters. Because of high variation in P_n observed for overcup oak leaves, two additional seedlings from each light environment were sampled for this species.

Curves were fit to photosynthetic light response data according to methods described in Givnish (1988). The model used for this procedure is defined in Equation 1.

$$P_n = [(P_{g\text{-}sat} \times PPFD) \div (K + PPFD)] - R_d \qquad (1)$$

For Equation 1, P_n is net photosynthesis, $P_{g\text{-}sat}$ is gross photosynthesis at leaf saturation, PPFD is photosynthetic photon flux density, K is the PPFD required to achieve half of $P_{g\text{-}sat}$, and R_d is the dark respiration rate. The light compensation point (LCP) for each leaf was calculated with Equation 2.

$$LCP = (-K \times R_d) \div (R_d - P_{g\text{-}sat}) \qquad (2)$$

Apparent quantum yield (φ) of each leaf was calculated with the first derivative of Equation 1 with PPFD set at LCP as presented in Equation 3.

$$\varphi = P_{g\text{-}sat} \times K \div (K^2 + 2K \times PPFD + PPFD^2) \qquad (3)$$

The effect of light availability on photosynthetic light response variables ($P_{n\text{-}sat}$, LCP, R_d, , K) and leaf morphology variables (blade area, leaf mass per area) were analyzed with analysis of variance procedures according to a completely random design for each species. All tests were conducted at an α of 0.05.

RESULTS AND DISCUSSION

Leaf Morphology

Leaves of all three oak species examined in this study exhibited morphological acclimation when seedlings were raised under 20 percent sunlight. Cherrybark oak showed the greatest blade area response with a 129 percent increase on leaves that developed under partial sunlight (table 1). Blade area of Nuttall oak increased 103 percent, while blade area of overcup oak showed a 67 percent increase. Observations on blade area increases from this study illustrate the magnitude of variation in morphological acclimation expressed by different North American oak species. Others have reported blade area increases of 110 percent for bur oak (*Quercus macrocarpa* Michaux), 108 percent for chinkapin oak (*Quercus muehlenbergii* Engelmann), and 208 percent for coast live oak (*Quercus agrifolia* Nee) when these species developed under partial sunlight (Callaway 1992, Hamerlynck and Knapp 1994).

Table 1—Morphological characteristics (mean ± standard error)[a] of leaves from three bottomland oak species raised under full (100 percent) or partial (20 percent) sunlight

Light Level	Cherrybark Oak	Nuttall Oak	Overcup oak
	---------------- Blade Area (cm^2) ----------------		
Full Sunlight (100 pct)	35.7 ± 1.8 b	25.6 ± 1.4 b	25.2 ± 1.2 b
Partial Sunlight (20 pct)	81.9 ± 4.8 a	52.1 ± 2.4 a	42.1 ± 2.5 a
	----------- Leaf Mass per Area (mg cm^{-2}) -----------		
Full Sunlight (100 pct)	11.9 ± 0.2 a	11.0 ± 0.2 a	9.8 ± 0.2 a
Partial Sunlight (20 pct)	7.0 ± 0.2 b	6.8 ± 0.1 b	6.3 ± 0.1 b

[a] Means in a column followed by the same letter are not different at α = 0.05.

Table 2--Photosynthetic light response variables (mean ± standard error)[a] for three bottomland oak species raised under full (100 percent) or partial (20 percent) sunlight

Light Level	Cherrybark Oak	Nuttall Oak	Overcup oak
	-------- Net Photosynthesis Rate (mol m^{-2} s^{-1}) --------		
Full Sunlight (100 pct)	12.9 ± 1.0 a	10.7 ± 0.7 a	10.5 ± 1.5 a
Partial Sunlight (20 pct)	6.8 ± 0.9 b	9.6 ± 1.2 a	7.5 ± 1.4 a
	------- Light Compensation Point (mol m^{-2} s^{-1}) --------		
Full Sunlight (100 pct)	18.3 ± 1.6 a	18.2 ± 3.4 a	22.9 ± 2.1 a
Partial Sunlight (20 pct)	9.8 ± 2.3 b	11.3 ± 0.7 a	7.1 ± 1.1 b
	--------- Dark Respiration Rate (mol m^{-2} s^{-1}) ---------		
Full Sunlight (100 pct)	0.9 ± 0.06 a	0.8 ± 0.14 a	0.9 ± 0.16 a
Partial Sunlight (20 pct)	0.4 ± 0.15 b	0.6 ± 0.16 a	0.4 ± 0.08 b
	--------------- Apparent Quantum Yield ---------------		
Full Sunlight (100 pct)	0.05 ± 0.006 a	0.04 ± 0.003 a	0.04 ± 0.006 b
Partial Sunlight (20 pct)	0.04 ± 0.005 a	0.05 ± 0.011 a	0.06 ± 0.004 a
	---------- Saturation Constant (mol m^{-2} s^{-1}) ----------		
Full Sunlight (100 pct)	319 ± 57 a	279 ± 53 a	319 ± 12 a
Partial Sunlight (20 pct)	226 ± 75 a	235 ± 35 a	142 ± 38b

[a] Means in a column followed by the same letter are not different at $\alpha = 0.05$.

Coupled with the increase in blade area, all species showed a reduced leaf mass per area when raised beneath partial sunlight (table 1). These reductions in mass per area ranged from 41 percent for cherrybark oak to 36 percent for overcup oak. Reductions in leaf mass per area probably result from a decrease in leaf thickness that can be attributed to a decrease in palisade cell stacking, a decrease in leaf cuticle thickness, and/or a decrease in epidermal and palisade cell thicknesses (Ashton and Berlyn 1994, Carpenter and Smith 1981, Jackson 1967). The range of response in mass per area observed between bottomland oaks in this study was comparable to other oak species endemic to the northern United States. Abrams and Kubiske (1990) reported that leaf mass per area decreased under low light availability by 35 percent for northern pin oak (*Quercus ellipsoidalis* E. J. Hill), 36 percent for northern red oak (*Quercus rubra* Linnaeus), 43 percent for bur oak and white oak (*Quercus alba* Linnaeus), and 56 percent for black oak (*Quercus velutina* Lamarck).

For many broadleaved tree species, leaves which developed under low light conditions will usually have enlarged leaf blades and a lower mass per area than those which have developed under ample light availability (Abrams and Kubiske 1990, Jackson 1967, Goulet and Bellefleur 1986). The three bottomland oaks examined in this experiment were no exception. Physiological function of oak seedlings growing in low light environments may benefit from this morphological acclimation. Leaf physiology of oak seedlings may be improved by several mechanisms including increasing the light gathering area of individual leaf blades, increasing the efficiency of harvesting diffuse sunlight because chloroplasts are closer to the leaf surface, and reducing the respiratory demand of leaves per unit area (Chow and others 1988, Hamerlynck and Knapp 1994, Man and Lieffers 1997, Kozlowski and others 1991).

Leaf Physiology

Photosynthetic light response curves revealed that acclimation of the photosynthetic mechanism to low light availability differed between the three bottomland oak species (figure 1, table 2). Cherrybark oak seedlings which developed beneath partial sunlight showed a 50 percent reduction in $P_{n\text{-}sat}$ (table 2). This is in contrast to $P_{n\text{-}sat}$ rates observed for Nuttall oak and overcup oak, which did not show a decrease when seedlings were raised under partial sunlight. The reduced photosynthetic capacity observed for cherrybark oak is consistent with another report on this species, and observations on other shade intolerant broadleaved species (Bazzaz and Carlson 1982, Gardiner and Krauss In Press, Kubiske and Pregitzer 1996). It is not known why Nuttall oak and overcup oak behaved differently, but a light environment effect on overcup oak may have been obscured by the high variance associated with $P_{n\text{-}sat}$ for this species (figure 1, table 2). Photosynthetic capacities of seedlings receiving full sunlight in this study were generally higher than reported observations on field-grown cherrybark oak and Nuttall oak seedlings (Gardiner and others In Press, Sung and others 1999).

In addition to decreased $P_{n\text{-sat},}$ cherrybark oak seedlings raised under partial sunlight exhibited a 55 percent decrease in R_d (table 2). R_d of overcup oak was similarly reduced, but R_d for Nuttall oak was not altered by light regime (table 2). A decrease in R_d would be expected to accompany reductions in leaf mass per area as noted earlier for these three oak species, because of the reduced cell volume associated with the lower leaf mass per area (Hamerlynck and Knapp 1994, McMillen and McClendon 1983). Results from other studies on cherrybark oak and Nuttall oak are contradictory to the findings in this study. Gardiner and Krauss (In Press) reported a decrease in leaf mass per area for cherrybark oak grown under partial sunlight, but a concomitant decrease in R_d was not measured on those seedlings. And, Nuttall oak grown beneath an eastern cottonwood (*Populus deltoides* Bartram ex Marshall) canopy showed reduced leaf mass per area with a concomitant decrease in R_d (Gardiner and others In Press). These conflicting results indicate that the relative change in leaf mass per area and other uncontrolled environmental factors probably contributed to the disparate results noted between studies. For example, leaf temperature can have a strong effect on R_d, and this variable likely differed between experiments. In the work published by Gardiner and others (In Press) and Gardiner and Krauss (In Press), leaf cuvette temperature was controlled during R_d measurements. Sampling techniques used in this study were not amenable to controlling cuvette temperature.

Associated to the reduced $R_{d,}$ LCP decreased 46 percent and 69 percent, respectively, for cherrybark oak and overcup oak leaves raised under partial sunlight (table 2). Though of overcup oak increased when seedlings developed under partial sunlight (figure 1, table 2), light environment did not alter φ of cherrybark oak, nor did it impact LCP or φ of Nuttall oak. Three other North American oaks exhibited similar reductions in LCPs when leaves were acclimated to low light environments (Kubiske and Pregitzer 1996, Hamerlynck and Knapp 1994). Results from those studies confirm the observation that LCPs were lowered primarily through decreased R_d rather than through an increased φ. However, the higher φ observed for overcup oak seedlings raised under partial sunlight in this study may have lead to a decreased K, which was not observed for cherrybark oak or Nuttall oak (table 2).

MANAGEMENT IMPLICATIONS

Though this study does not consider whole-plant response to light environment, several implications for management of bottomland oak regeneration may be inferred from leaf-level response patterns. First, stand structure of many mixed hardwood forests restricts availability of sufficient light to maximize seedling carbon assimilation. The three bottomland oaks studied appear to require more than 25 to 30 percent of available sunlight for light saturation requirements. Light availability in the understory of mixed bottomland hardwood stands is typically less than 10 percent of available sunlight (Jenkins and Chambers 1989, Lockhart

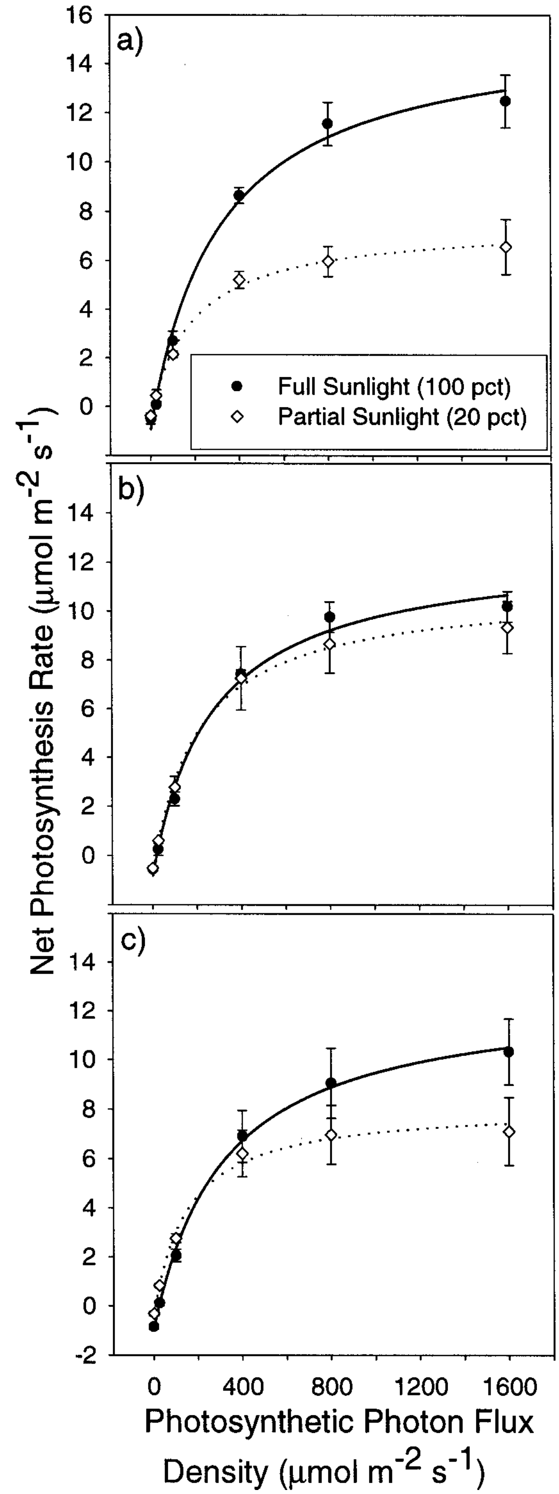


Figure 1—Photosynthetic light response of cherrybark oak (a), Nuttall oak (b) and overcup oak (c) seedlings raised under full (100 percent) or partial sunlight (20 percent).

and others 2000). This study provides physiological evidence supporting the argument that managers will have to implement practices that provide stand structures which improve understory light availability to promote establishment and growth of bottomland oak reproduction (Lockhart and others 2000).

Secondly, bottomland oak seedlings appear to have different light requirements. For example, establishment and growth of cherrybark oak seedlings might require a greater level of understory light availability than other species. The complex aspect of this implication is that bottomland oak species are often found on different sites with different species associations. So, a treatment that provides sufficient light for overcup oak in a slough, may not be adequate for facilitating establishment and growth of cherrybark oak on a ridge.

Related to the second implication is that the different light requirements for each species may also directly effect the length of time seedlings can remain in an understory before being released. Species like Nuttall oak or overcup oak may persist in the reproduction pool of the understory longer than a species like cherrybark oak. Indeed, Johnson (1975) noted that Nuttall oak could persist in the understory for 15 years if seedlings received about 2 hours of direct sunlight a day.

A final management implication gathered from this research revolves around the observation that bottomland oaks differed in their degree of acclimation to light availability. The physiological acclimation observed for cherrybark oak was in association with relatively large shifts in leaf morphology. The implication is that oak seedlings, particularly cherrybark oak, will have to develop a new leaf flush to respond to a richer light environment. It is not known if a species like Nuttall oak, which shows relatively little morphological and physiological acclimation to light availability, can respond quicker to release than a species like cherrybark oak. Nevertheless, oak seedlings will probably require acclimation time before responding to release. A similar finding was noted by Gardiner and Hodges (1998) who considered acclimation of cherrybark oak seedling morphology under various light levels. The slow response to release by cherrybark oak may be seen in the research of Lockhart and others (2000) and Janzen and Hodges (1985). In each of these studies, seedlings required about 3 years before significant response was realized. Regeneration strategies will have to account for this delayed response.

LITERATURE CITED

Abrams, M. D.; Kubiske, M.E. 1990. Leaf structure characteristics of 31 hardwood and conifer tree species in central Wisconsin: influence of light regime and shade-tolerance rank. Forest Ecology and Management. 31: 245-253.

Ashton, P. M. S.; Berlyn, G. P. 1994. A comparison of leaf physiology and anatomy of *Quercus* (section *Erythrobalanus*-Fagaceae) species in different light environments. American Journal of Botany. 81: 589-597.

Bazzaz, F. A.; Carlson, R. W. 1982. Photosynthetic acclimation to variability in the light environment of early and late successional plants. Oecologia. 54: 313-316.

Callaway, R. M. 1992. Morphological and physiological responses of three California oak species to shade. International Journal of Plant Science. 153: 434-441.

Carpenter, S. B.; Smith, N. D. 1981. A comparative study of leaf thickness among southern Appalachian hardwoods. Canadian Journal of Botany. 59: 1393-1396.

Chambers, J. L.; Stuhlinger, H. C.; Clifton, R. G. P. 1987. Regeneration of bottomland hardwood sites by pre-harvest planting. In: Phillips, D.R., comp. Proceedings of the fourth biennial southern silvicultural research conference; 1986 November 4-6; Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 125-128.

Chow, W. S.; Qian, L.; Goodchild, D. J.; Anderson, J. M. 1988. Photosynthetic acclimation of *Alocasia macrorrhiza* (L.) G. Don to growth irradiance: structure, function and composition of chloroplasts. Australian Journal of Plant Physiology. 15: 107-122.

Gardiner, E. S.; Hodges, J. D. 1998. Growth and biomass distribution of cherrybark oak (*Quercus pagoda* Raf.) seedlings as influenced by light availability. Forest Ecology and Management. 108: 127-134.

Gardiner, E. S.; Krauss, K. W. In Press. Photosynthetic light response of flooded cherrybark oak (*Quercus pagoda* Raf) seedlings grown under two light regimes. Tree Physiology.

Gardiner, E. S.; Schweitzer, C. J.; Stanturf, J. A. In Press. Photosynthesis of Nuttall oak (*Quercus nuttallii* Palm.) seedlings interplanted beneath an eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) nurse crop. Forest Ecology and Management.

Gardiner, E. S.; Yeiser, J. L. 1999. Establishment and growth of cherrybark oak seedlings underplanted beneath a partial overstory in a minor bottom of southwestern Arkansas: first year results. In: Haywood, J. D., ed. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16-18; Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 171-175.

Givnish, T. J. 1988. Adaptation to sun and shade: a whole-plant perspective. Australian Journal of Plant Physiology. 15: 63-69.

Goulet, F.; Bellefleur, P. 1986. Leaf morphology plasticity in response to light environment in deciduous tree species and its implication on forest succession. Canadian Journal of Forest Research. 16: 1192-1195.

Hamerlynck, E. P.; Knapp, A. K. 1994. Leaf-level responses to light and temperature in two co-occurring *Quercus* (Fagaceae) species: implications for tree distribution patterns. Forest Ecology and Management. 68: 149-159.

Hodges, J. D.; Gardiner, E. S. 1993. Ecology and physiology of oak regeneration. In: Loftis, D.; McGee, C. E., ed. Oak regeneration: serious problems, practical recommendations. Symposium Proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 54-65.

Hodges, J. D.; Janzen, G. 1987. Studies on the biology of cherrybark oak: recommendations for regeneration. Proceedings of the fourth biennial southern silvicultural research conference; 1986 November 4-6; Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 133-139.

Jackson, L. W. R. 1967. Effect of shade on leaf structure of deciduous tree species. Ecology. 48: 498-499.

Janzen, G. C.; Hodges, J. D. 1985. Influence of midstory and understory vegetation removal on the establishment and development of oak regeneration. In: Shoulders, E., ed. Proceedings of the third biennial southern silvicultural research conference; 1984 November 7-8; Atlanta, GA. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 273-278.

Jenkins, M. W.; Chambers, J. L. 1989. Understory light levels in mature hardwood stands after partial overstory removal. Forest Ecology and Management. 26: 247-256.

Johnson, R. L. 1975. Natural regeneration and development of Nuttall oak and associated species. Res. Pap. SO-104. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 12 p.

Johnson, R. L. 1981. Oak seeding - it can work. Southern Journal of Applied Forestry. 5: 28-33.

Johnson, R. L.; Deen, R. T. 1993. Prediction of oak regeneration in bottomland forests. In: Loftis, D.; McGee, C. E., ed. Oak regeneration: serious problems, practical recommendations. Symposium Proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 146-155.

Kozlowski, T. T.; Kramer, P. J.; Pallardy, S. G. 1991. The physiological ecology of woody plants. New York: Academic Press, Inc. 657 p.

Kubiske, M. E.; Pregitzer, K. S. 1996. Effects of elevated CO_2 and light availability on the photosynthetic light response of trees of contrasting shade tolerance. Tree Physiology. 16: 351-358.

Lockhart, B. R.; Hodges, J. D.; Gardiner, E. S. 2000. Response of advance cherrybark oak reproduction to midstory removal and shoot clipping. Southern Journal of Applied Forestry. 24: 45-50.

Man, R.; Lieffers, V. J. 1997. Seasonal photosynthetic responses to light and temperature in white spruce (*Picea glauca*) seedlings planted under an aspen (*Populus tremuloides*) canopy and in the open. Tree Physiology. 17: 437-444.

McMillen, G. G.; McClendon, J. H. 1983. Dependence of photosynthetic rates on leaf density thickness in deciduous woody plants grown in sun and shade. Plant Physiology. 72: 674-678.

Nix, L. E.; Haymond, J. L.; Woodrum, W. G., III. 1985. Early results of oak enrichment plantings in bottomland hardwoods of South Carolina. In: Shoulders, E., ed. Proceedings of the third biennial southern silvicultural research conference; 1984 November 7-8; Atlanta, GA. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 154-158.

Putnam, J.A.; Furnival, G.M.; McKnight, J.S. 1960. Management and inventory of southern hardwoods. Agricultural Handbook No. 181. Washington, DC. U.S. Department of Agriculture, Forest Service. 102 p.

Sung, S. S., Kormanik, P. P.; Zarnoch, S. J. 1999. Photosynthetic characteristics of five hardwood species in a mixed stand. In: Haywood, J. D., ed. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16-18; Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 180-184.

Young, G. L.; Karr, B. L.; Leopold, B. D.; Hodges, J. D. 1995. Effect of greentree reservoir management on Mississippi bottomland hardwoods. Wildlife Society Bulletin. 23: 525-531.

RESPONSES OF TREE CROWN CONDITIONS TO NATURAL AND INDUCED VARIATIONS IN THROUGHFALL

Theodor D. Leininger[1]

Abstract—Concentrations of greenhouse gases, such as carbon dioxide, methane, and oxides of nitrogen, in the atmosphere are predicted to double in the next one hundred years. Forecasts of climatic variation across the southeastern United States resulting from these increases range from higher average temperatures and decreased summertime precipitation to lower maximum temperatures and greater precipitation. Since 1993, the effects of increased and decreased precipitation have been studied on an upland hardwood forest in the Walker Branch Watershed near Oak Ridge, TN. Soil moisture was altered by gravity-driven transport of throughfall from a 'dry' (-33 percent of ambient) treatment plot across an ambient treatment plot to a 'wet' (+33 percent of ambient) treatment plot. Beginning in August 1996, crown conditions of saplings and mature trees were monitored annually for responses to seasonal and treatment-related differences in soil moisture. The crown condition classification system developed by the USDA Forest Service, Forest Health Monitoring Program (FHMP) was used to rate tree crowns according to five variables: crown diameter, live crown ratio, foliage density, foliage transparency, and crown dieback. Preliminary analyses indicate differences in crown condition variables between soil moisture treatments and between years within treatments. A full analysis of five years of data, including August 2000, is presented. Results are discussed in relation to climate change predictions for the southeastern United States, and the usefulness of the FHMP crown condition classification system for monitoring forest health in a changing environment.

INTRODUCTION

Researchers have predicted concentrations of atmospheric greenhouse gases, such as carbon dioxide, methane, and oxides of nitrogen, to double in the next one hundred years (Edmonds and others 1984; Freidli and others 1986), thereby increasing the greenhouse effect and leading to an estimated increase in global mean temperature of between 1.5 and 4.5° Celsius (National Academy of Sciences 1983). Uncertainty exists in the predictions of how climate will be altered by the predicted increases in greenhouse gases. Depending on which climate change models are used, forecasts of climatic variation resulting from increases in greenhouse gases range from decreases in summertime precipitation from 5 to 10 percent and increases in wintertime precipitation (Karl and others 1991) to greater summertime precipitation with lower maximum temperatures and higher minimum temperatures (Idso and Balling 1992).

The Throughfall Displacement Experiment (TDE), located on Walker Branch Watershed at the Oak Ridge National Laboratory near Oak Ridge, Tennessee, was designed to study changes in ecological processes that might occur by decreasing hydrologic inputs to one area of a forest while increasing them in an adjacent part of the forest (Hanson and others 1998). Since 1996, indicators of tree crown health have been monitored in response to throughfall displacement in the canopy of this upland hardwood forest in eastern Tennessee. Measurements of crown responses to either increased or decreased soil moisture resulting from displaced throughfall, were estimated for crown variables using a protocol developed for the Forest Health Monitoring Program (FHMP), State and Private Forestry of the US Forest Service (USDA Forest Service 2001).

This research was designed to utilize the unique hydrological manipulations occurring on the TDE site in an attempt to document any changes in tree crown appearance occurring from decreased or increased soil moisture resulting from the manipulation. This research has as its basis general principles of ecophysiological responses of plants to their environment. For example, a plant growing in soil that begins to dry out will typically allocate more carbon resources to roots at the expense of shoots in an effort to obtain more water. If this effect were to become great enough, tree crowns with reduced mass would appear more transparent, less dense, and perhaps exhibit branch dieback. These crown symptoms are typical of those associated with oak decline, a disease syndrome common in eastern hardwood forests (Ammon and others 1989) and often triggered by drought events (Maass 1989, Myers and Killingsworth 1992, Tainter and others 1990). An objective of this study was to determine the usefulness of the FHMP crown rating protocol in evaluating oaks (*Quercus* spp.) in decline.

[2]Project Leader, USDA Forest Service, Southern Research Station, Center for Bottomland Hardwoods Research, P.O. Box 227, Stoneville, Mississippi, 38776

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

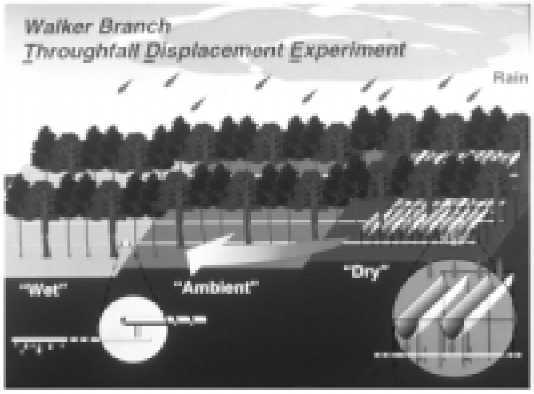


Figure 1—Schematic diagram of the Throughfall Displacement Experiment, Walker Branch Watershed, Oak Ridge National Laboratory, Oak Ridge, TN. Throughfall is captured in plastic troughs beneath the canopy of the Dry plot, flows by gravity through pvc pipes across the Ambient plot, and is released through small holes onto the Wet plot.

METHODS

The site for the Throughfall Displacement Experiment was chosen because of its uniform slope, consistent soils, a reasonably uniform distribution of vegetation, and its position just below the ridge top of the Walker Branch Watershed. The forest on the Walker Branch Watershed is upland hardwood dominated by white (*Quercus alba* L.) and chestnut (*Q. prinus* L.) oaks, sugar maple (*Acer saccharum* Marsh.), and yellow-poplar (*Liriodendron tulipifera*) in the overstory, red maple (*A. rubrum* L.) and blackgum (*Nyssa sylvatica* var. *sylvatica* Marsh.) in the midstory, and flowering dogwood (*Cornus florida* L.) and sourwood (*Oxydendrum arboreum* (L.) DC.) in the understory. There are about 20 tree species on the watershed. Changes in ecological processes resulting from this large-scale manipulation of throughfall will be evaluated in light of the more than 25 years of reference data collected on the Walker Branch Watershed. Complete information about the TDE study is available on the Internet at: www.esd.ornl.gov/programs/WBW/TDEAAAAA.HTM.

Since 1993, one third of the throughfall released by the forest canopy on the TDE has been captured by an array of troughs and is moved from one section of the forested area by way of a gravity-fed system of pvc pipes to another section of forest (figure1). The area from which one third of throughfall is being removed is the DRY plot, the area receiving the water captured on the DRY plot is the WET plot, and the area in between which receives an unaltered amount of throughfall is the AMBIENT (AMB) plot. Thus, in terms of ambient throughfall, the DRY plot receives 67 percent of ambient throughfall while the WET plot receives 133 percent of ambient throughfall.

Throughfall is intercepted in about 2000 subcanopy troughs (0.3 x 5 meters) suspended above the forest floor on the DRY treatment plot and is then channeled into the pvc pipe system (figure 1). These catchment-pvc pipe systems have been placed at regular intervals from the top of the site to the bottom. Each treatment plot is 80 x 80 meters. Reductions in soil moisture on the DRY plot were expected to be equivalent to the driest growing seasons of the 1980's drought, which resulted in reduced tree growth of some species.

Each 80 x 80 meter plot is further sub-divided into 64 sub-plots with 10 x 10 meter dimensions. Treatment plots are surrounded by a buffer of 10 x 10 m sub-plots. Each tree on the site greater than 10 centimeters was mapped and measured for height and diameter at the beginning of the study and is remeasured on a regular basis. The health of 30 randomly selected trees of various species throughout the understory, midstory, and overstory on each treatment plot was estimated using the FHMP crown condition rating protocol (USDA Forest Service 2001).

The FHMP crown condition rating protocol consists of five variables: diameter, live crown ratio, foliage density, foliage transparency, and dieback. Crown diameter is the average of the widest transect anywhere in the crown and the transect perpendicular to that, measured on the ground in meters. Live crown ratio is the percentage of the length of the live crown compared to total tree height. Foliage density is the percentage of crown branches and leaves that block light coming through a one-dimensional view of the crown taken as a whole. Foliage transparency is the percentage of the amount of skylight visible through the live, normally foliated portion of the crown viewed in the same manner as density. Transparency is the opposite of density. The estimate of crown dieback is a measure of branch mortality as a percentage of the total possible live crown, including dead branches. Dieback begins at the terminal portions of a branch and proceeds toward the trunk or base of the live crown.

Estimates of crown density and transparency were made using a standardized, printed scale that ranges from 5 percent to 95 percent in increments of 5 percent. Each variable except diameter was estimated by two people and averaged for each tree evaluated. The five variables were estimated in mid August from 1996 to 2000. The throughfall manipulation treatment was in effect three years when crown variable measurements were begun. Two-way ANOVAs were performed on the data for treatments by years and years by treatments. Data from the 30 trees sampled on each plot were used in the analysis without regard to tree crown position in the canopy. Percentage

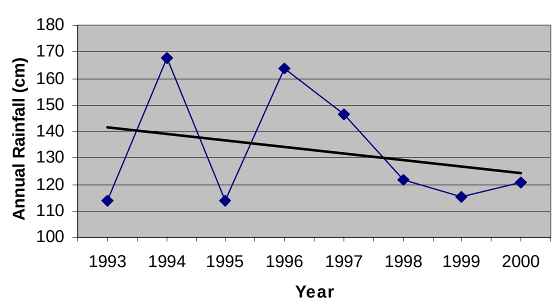


Figure 2—Annual rainfall (with trend line) from 1993 to 2000 at the Throughfall Displacement Experiment site, Walker Branch Watershed, Oak Ridge, TN.

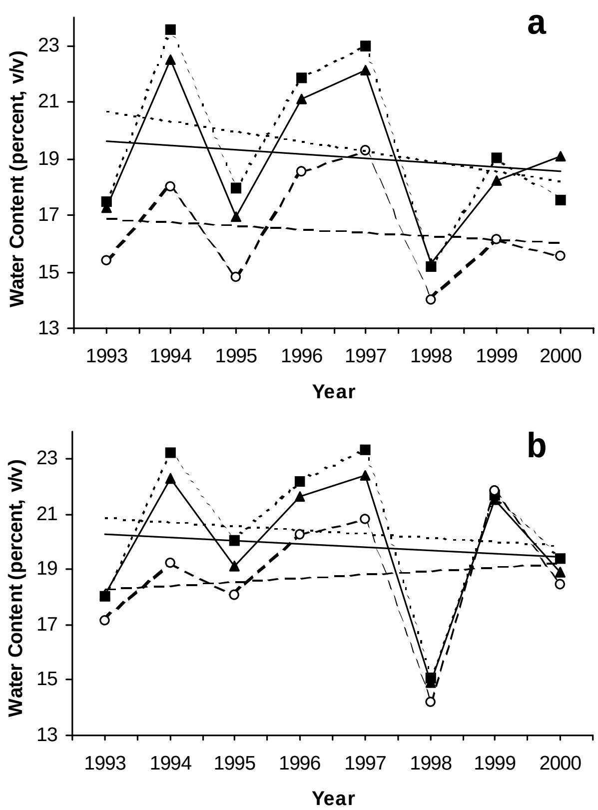


Figure 3— Average soil water contents (percent, v/v) and trend lines for the a) 0 to 35-cm and b) 0 to 70-cm soil profiles on the Wet (■), Ambient (▲), and Dry (❍) plots.

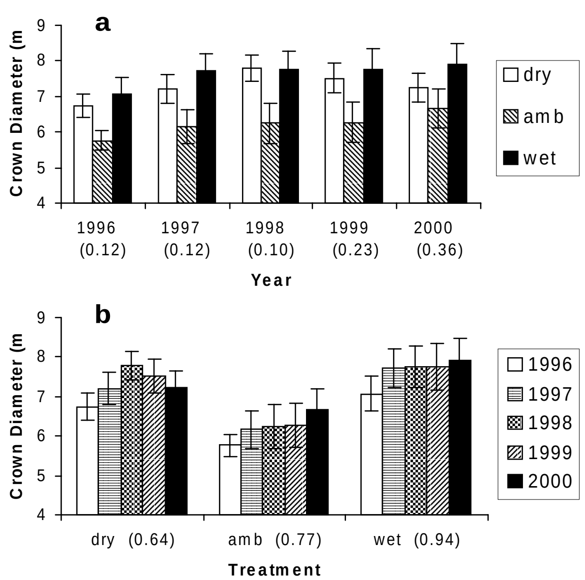


Figure 4—Mean crown diameters (“ s.e.m.) of sample trees for a) treatments by years and b) years by treatments. Numbers in parentheses on the x-axis are p-values from the ANOVA tests.

data were transformed using the arcsine function prior to analysis. Tukey's multiple comparisons tests were used to compare variable means.

RESULTS AND DISCUSSION

Rainfall Data

Annual total rainfall at the TDE varied from lows of about 114 centimeters in 1993 and 1995 to a high of about 168 cm in 1994; 1996 had the second highest rainfall (figure 2). Rainfall in five of the eight years was below the trend line of decreasing average precipitation over the treatment period. Starting in 1993, there was a rainfall pattern of low, high, low, and high, followed by a four-year trend of decreasing rainfall.

Soil Moisture Data

This same general increasing and decreasing pattern and overall decreasing trend is evident in soil water content data, as measured by time-domain reflectometry on the three treatment plots, measured in the 0 to 35-cm and 0 to 70-cm layers of soil (figure 3a and b). The effect of throughfall displacement treatments is visible in the soil moisture data from the 0-35 cm layer, with a greater separation evident between the DRY and AMB treatments than between WET and AMB treatments. Treatment separation is less apparent as a function of soil moisture averaged over 70 cm of soil profile.

Crown Diameters

Average annual crown diameters were not affected by throughfall treatments during the five-year measurement period (figure 4a). The average tree crown on the AMB plot tended to be smaller than tree crowns on the DRY and WET plots when first measured in 1996 and they remained that way for the next four years. Crown diameters did not vary from year to year between throughfall treatments (figure 4b).

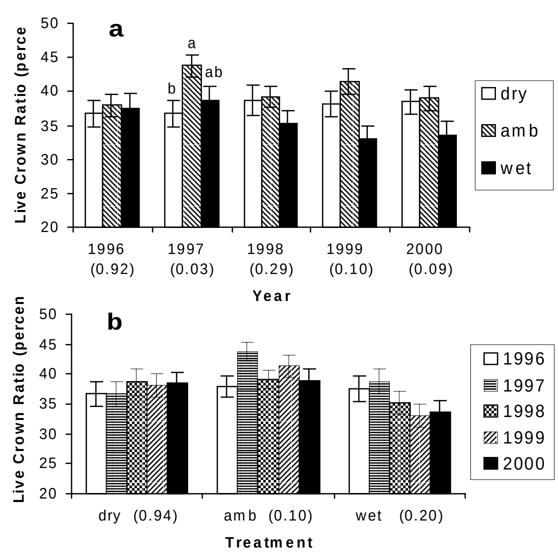


Figure 5—Mean live crown ratios (“ s.e.m.) of sample trees for a) treatments by years and b) years by treatments. Numbers in parentheses on the x-axis are p-values from the ANOVA tests. Means with different lowercase letters, in a year or treatment category, differ at p=0.05 by Tukey's mean comparison tests.

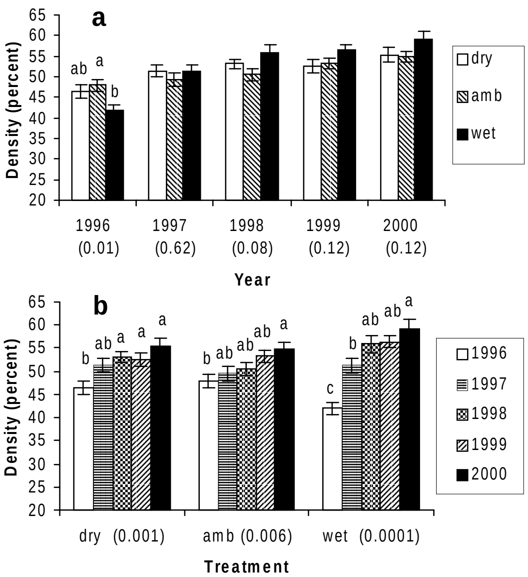


Figure 6—Mean crown densities (“ s.e.m.) of sample trees for a) treatments by years and b) years by treatments. Numbers in parentheses on the x-axis are p-values from the ANOVA tests. Means with different lowercase letters, in a year or treatment category, differ at p=0.05 by Tukey's mean comparison tests.

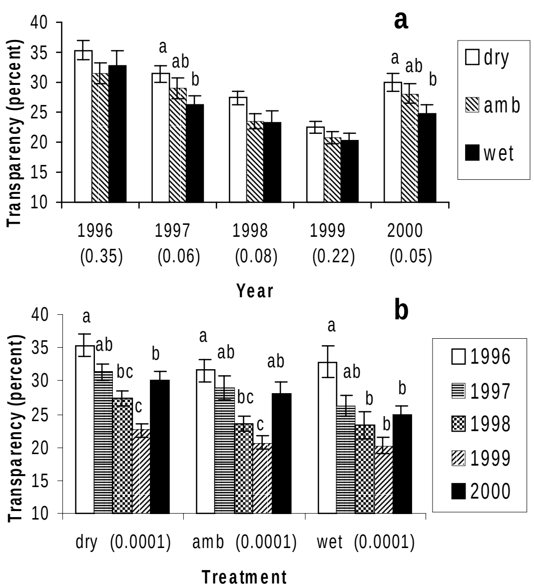


Figure 7—Mean crown transparencies (“ s.e.m.) of sample trees for a) treatments by years and b) years by treatments. Numbers in parentheses on the x-axis are p-values from the ANOVA tests. Means with different lowercase letters, in a year or treatment category, differ at p=0.05 by Tukey's mean comparison tests.

Live Crown Ratios

Analysis revealed that the average live crown ratio on the AMB plot was greater than that on the DRY plot in 1997, but it is not clear what this means from a physiological standpoint (figure 5a). It is interesting to note that on the WET plot, there is a tendency for the average live crown ratio to decrease over time (figure 5b). This decrease is not statistically significant, but suggests a physiological adjustment of crown length due to added soil moisture, although in the opposite direction of what might be expected. An examination of physiological variables such as water use efficiency and chlorophyll concentrations would need to be done to determine if this was a meaningful trend, and to determine what other factors might be involved.

Crown Density

Average crown density on the AMB plot was greater than that on the WET plot in 1996, but this relationship was not consistent with trends in average crown densities measured the next four years when crowns on the WET plot tended to be denser (figure 6a). Crown densities increased consistently on all three throughfall treatment plots from 1996 to 2000, and this in light of overall decreasing rainfall and soil moisture over those years (fig 6b). One might expect crowns to be less well foliated under a drying soil regime.

Crown Transparency

Tree crowns tended to exhibit less transparency, which means that there was less light visible through them, as soil moisture availability increased on the plot (figure 7a). These differences were statistically significant in 1997 and 2000. Transparency also tended to decrease on all three throughfall treatments from 1996 to 2000 as rainfall tended to decrease over the same period (figure 7b). Decreasing transparency is consistent and expected in conjunction with the consistent increases in density measured for all plots. It is interesting to note the increase in transparency on all plots in 2000, which was the third in a series of three dry years (figure 7b). It could be that an effect of three consecutive dry years is becoming evident.

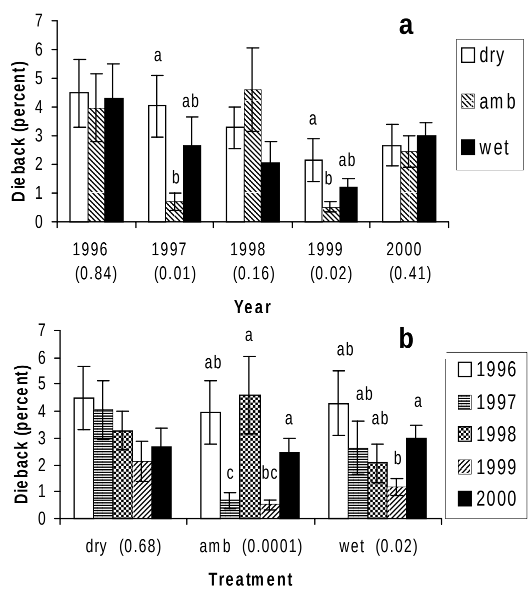


Figure 8—Mean crown dieback (“ s.e.m.) of sample trees for a) treatments by years and b) years by treatments. Numbers in parentheses on the x-axis are p-values from the ANOVA tests. Means with different lowercase letters, in a year or treatment category, differ at p=0.05 by Tukey's mean comparison tests.

Crown Dieback

Crown dieback was quite variable across throughfall treatments over the years. In 1997 and 1999, dieback was greater on the DRY plot than on the AMB plot (figure 8a), which makes sense physiologically since drought-stressed trees should have more dieback than trees receiving adequate moisture. Dieback tended to decrease from 1996 to 2000 on all throughfall treatment plots as rainfall and soil moisture tended to decrease (figure 8b), which is opposite of expectations. Again, there is an increase in dieback on all plots in 2000, the third of three dry years.

CONCLUSIONS

The current transfer of one third of the throughfall from the DRY plot to the WET plot on the TDE is probably not sufficient to cause large enough visual differences in crown health to be differentiated using the FHMP crown rating protocol. While some crown condition responses make sense from a biological and physiological standpoint, particularly for transparency and dieback, many of the results are either too variable or are opposite of what might be expected biologically. The principal investigators of the TDE have discussed the merits of doubling throughfall displacement from one third to two thirds in an effort to increase responses of large trees to hydrologic manipulation. Early sapling mortality patterns showed more dogwood dying on the DRY plot then on the AMB and WET plots; however, the long-term pattern shows reductions of dogwood and red maple mortality on the WET plot compared to that on the Tree responses are confounded by the fact that large trees with large root systems are situated in fairly small plots in the experimental area. There is little doubt that roots of the larger trees are growing in other treatment plots, or outside the treatment area. As a result, these data need to be analyzed after having stratified them according to crown position, diameter, and perhaps species. This might reveal treatment responses not seen in the present analysis of the combined data set. More detailed regression analyses using physiological and site variables are currently underway, the results of which will be published as a chapter in a Springer-Verlag book describing all the various research efforts and current findings from the TDE site.

ACKNOWLEDGMENTS

The author wishes to thank the following employees of the US Forest Service, Center for Bottomland Hardwoods Research for their help with data collection and analysis: Curt McCasland, Ty Swirin, Danny and Stephanie Skojac, Lisa Nonneman, and Jessica Benson. The author also thanks Paul Hanson and other personnel of the Environmental Sciences Division of Oak Ridge National Labs for access to the TDE and various data sets from the TDE.

LITERATURE CITED

Ammon, V.; Nebeker, T.E.; Filer, T.H.; McCracken, F.I.; Solomon, J.D.; Kennedy, H.E. 1989. Oak decline. Mississippi Agricultural and Forestry Experiment Station Technical Bulletin 161, Mississippi State University, MS. 15 p.

Edmonds, J.A.; Reilly, J.; Trabalka, J.R.; Reichle; D.E. 1984. An analysis of possible future retention of fossil fuel CO_2. DOE OR/21400-1, Washington, D.C.: U.S. Dept. of Energy.

Friedli, H.L.; Oescher, H.; Siegenthaler, H.; Stauffer, U.; Stauffer, B. 1986. Ice core record of the C^{13}/C^{12} ratio of atmospheric CO_2 in the past two centuries. Nature. 324: 237-238.

Hanson, P.J.; Todd, D.E.; Amthor, J.S. 2001. A six year study of sapling and large-tree growth and mortality responses to natural and induced variability in precipitation and throughfall. Tree Physiology. 21: 345-358.

Hanson, P.J.; Todd, D.E.; Huston, M.A.; Joslin, J.D.; Croker, J.; and Augé, R. M. 1998. Description and field performance of the Walker Branch Throughfall Displacement Experiment: 1993-1996, ORNL/TM-13586, Oak Ridge, TN: Oak Ridge National Laboratory, 47 p.

Idso, S.B.; Balling, R.C., Jr. 1992. US temperature/precipitation relationships: implications for future ‘greenhouse’ climates. Agricultural and Forest Meteorology. 58: 143-147.

Karl, T.R.; Heim, R.H., Jr.; Quayle, R.G. 1991. The greenhouse effect in central North America: If not now, when? Science. 251: 1058-1061.

Maass, D. 1989. The 1988 drought:somelikely impacts on Northern forests. Northern Logger and Timber Processor. 5: 18-40.

Myers, C.C.; Killingsworth, P.A. 1992. Growth and mortality of black oak in southern Illinois. Northern Journal of Applied Forestry. 9(1): 33-39.

National Academy of Sciences. 1983. Changing Climate. Report of the carbon dioxide assessment committee. Washington, D.C: National Academy Press,

Tainter, F.H.; Retzlaff, W.A.; Starkey, D.A.; Oak, S.W. 1990. Decline of radial growth in red oaks is associated with short-term changes in climate. European Journal of Forest Pathology. 20: 95-105.

USDA Forest Service. 2001. Phase 3 Field Guide. Section 12. Crowns: Measurements and Sampling. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station, Forest Inventory and Analysis. 21 p. <http://fia.fs.fed.us/library.htm#Manuals>

FOOD RESERVES IN MOUNTAIN LONGLEAF PINE ROOTS DURING SHOOT ELONGATION

Charles H. Walkinshaw and William J. Otrosina[1]

Abstract—Survival and growth of longleaf pine seedlings depends upon a well-developed root system. Soil moisture is also critical for the seedling to emerge from the grass-stage. When longleaf pine seedlings emerge from the grass stage, they grow rapidly in height and diameter. Branches are often few in number and, if present, may have low photosynthesis rates. This growth pattern is seen on all longleaf pine sites, including low fertility mountain soils. Root growth patterns on poor soils suggest that biochemical adaptations are occurring when compared to those of Coastal Plain soils. Our results show that roots of mountain longleaf pine have a normal anatomy but also have unusual amounts of starch when compared to loblolly pine roots growing during phenologically equivalent time periods. Longleaf pine roots from mountain soils appeared large in diameter and appeared to grow much nearer the soil surface than roots we observed from Coastal Plain longleaf pine. Among the variables examined to determine root food reserves, numbers of starch grains were found to be easiest to quantify. Starch grains were large in size and uniformly filled root cells. Nuclear staining served to verify the observed root cells were healthy. These results yield methodology potentially useful in assessment of health and productivity of longleaf pine.

INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) is considered as resistant or highly tolerant to many diseases and insects that adversely affect other southern pine species (Derr 1966, Mann 1969). Under some conditions, prescribed burning has been associated with increased mortality of mature longleaf pine (Otrosina and others 2000). The increased mortality is also associated with presence of certain root infecting fungi (Ophiostomatoid fungi such as *Leptographium* species and the root rot pathogen *Heterobasidion annosum* (Fr.)Bref.) not previously thought to be pathologically important in this tree species but may be indicators of ecosystem stress. This study is part of an ongoing project designed to measure and explain root mortality in longleaf pines that receive prescribed fire infrequently or have prescribed fire reintroduced after a long interval. To accomplish this goal, we are employing histological and statistical methods to identify variables in roots that are associated with this mortality. We attempt to quantitatively and qualitatively characterize fine root tissues we define as healthy; those roots having high food reserves, low mortality, and normal cortical cell nuclei. Means for histological variables we investigated can become standards to evaluate efficacy, effect, and consequences of fire and other silvicultural practices as well as to interpret other root pathological activity reported previously (Otrosina and others 2000).

MATERIALS AND METHODS

Longleaf pine saplings used in this study were approximately 10 years old and located in the Talledega National Forest (figure 1). Roots from 12 saplings undergoing rapid height growth were chosen because they must develop rapidly and extensively to support height growth rates of 1.0 to 2.0 meters per year. The stand of several thousand sapling longleaf pine was approximately 3.5 m in height. The randomly sampled trees ranged from 6.0 to 8.0 cm d.b.h. (diameter at breast height). Buds had not expanded at the time of sampling.

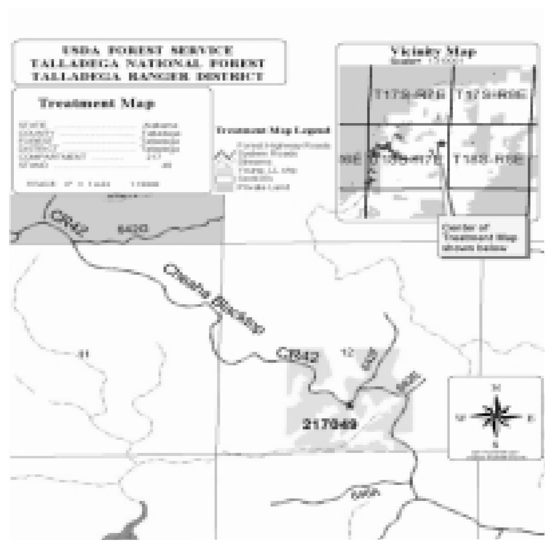


Figure 1—Location of longleaf pine saplings used in this study.

Roots were also sampled from randomly selected adult longleaf pine in northwestern South Carolina (Savannah River Site, New Ellenton SC). Trees sampled at this

[1]Emeritus Forest Service, Plant Pathologist, Institute of Tree-Root Biology, USDA Forest Service, 320 Green Street, Athens, GA 30602, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Description of variables used in longleaf pine root histological studies

VARIABLE	P-VALUE [a]	DEFINITION
Abnormal Cambium	0.500	Cambial initials reduced in number or out of alignment. Necrotic derivations present.
Bark Formed	0.0001	Intact layer of bark cells similar to those found in the stem encompasses the root. Protects the root from injuries and microbial invasion.
Dead Roots	0.231	Cells with ruptured membranes. Tannin adhere to cell walls. Chromatin abnormal. Starch grains may or may not be present.
Large Root	0.0112	Roots more than 3 mm in diameter.
Nuclear Stain (abnormal)	0.231	Indicates degeneration (pyknosis) of chromatin.
Number Of Starch Grains	0.0189	Number of starch-containing plastids per cell viewed at a single focus per cell length at 100 to 500 diameters.
Small Roots	0.0326	Actual measurement of roots less than 3 mm.
Size of Starch Grains	0.0008	Size of starch grains scored as 1, 2, or 3 for each cell. Range in actual size was 0.5 to 4.0 microns.
Starch Use	0.0001	Starch grains 50 percent or more hydrolyzed.
Tannin	0.5393	Accumulation of excess tannin-containing cells in the cortex, rays and inner xylem.

[a] From ANOVA that compared values for variables in roots of 12 saplings.

Table 2–Variation in starch grain number, size, and use in fine roots of sapling longleaf pines

Sapling	Number of roots	Number of grains per cell	Relative size of grains [a]	Starch use index [a]
1	21	20.2	2.67	0.048
2	14	21.2	2.78	0.071
3	23	17.3	2.30	0.087
4	15	16.3	2.40	0.067
5	16	15.1	2.25	0.125
6	14	17.1	2.50	0.214
7	13	17.5	2.08	0.231
8	19	21.3	2.68	0.579
9	14	18.1	2.43	0.0714
10	18	18.5	2.89	0.444
11	24	17.0	2.71	0.083
12	19	18.5	2.74	0.211

[a] See table 1 for definitions.

location were from unburned plots that are part of a prescribed burning study previously reported (Otrosina and others 2000). The Alabama and South Carolina locations are at equivalent latitudes and under management by the USDA Forest Service. The adult trees ranged from 25 to 35 cm d.b.h. Buds had not expanded at the time of sampling.

From both locations, roots within 8.0 cm of the soil surface were collected from the main laterals and immediately placed in formalin:acetic acid:alcohol (FAA) fixative solution (Sass 1951). After several weeks in FAA, root pieces 3-4 mm long were rinsed thoroughly with 70 percent ethanol, dehydrated, in 100 percent ethanol, paraffin embedded, and sectioned and 8-15 microns. Staining involved a number of acidic and basic dyes (Hass 1980, Horobin and Bancroft 1998, Preece 1972). See references for pertinent literature regarding detailed histological procedures.

Root tissue mortality was scored when nuclear stains were abnormal and expressed as percentage of fine roots examined. Abnormally staining nuclei appeared as grey to dull brown rather than red or blue-grey in a microscopic field of about 100 microns in radius. Other variables measured are in table 1.

RESULTS

Roots from the 12 mature longleaf pines had less starch, more tannin, and higher mortality than that of saplings:

VARIABLE	SAPLING [a]	MATURE [a]
No. starch grains	15.1 - 21.3	1.60 - 6.40
Tannin [b]	.048 - .261	0.54 - 0.90
Mortality [b]	.000 - .071	0.10 - 0.67

[a] Values indicate range.
[b] Proportion of roots with this variable.

Nuclei stained normally in roots from 11 of the 12 saplings and in 50 percent of the roots from adult trees. A similar result was obtained in evaluating cambial condition: 96.2 percent were normal in sapling roots and only 76.2 percent were normal for the mature trees. Means for the roots from the 12 saplings were not significantly different for the following variables: abnormal cambium, root mortality, nuclear stain, small roots, and tannin accumulation. Also, for the saplings, variables with the largest and statistically significant differences among means occurred in size of starch grains and starch grain use (tables 1 and 2). Roots from sapling number 8 had significantly (α =0.05) higher numbers of starch grains (21.3) and greater use of starch (0.579) than the other root specimens. Moreover, the proportion of tannin-containing cells in roots from this tree was only 0.0526 compared to an over all mean of 0.124.

DISCUSSION

Roots of saplings appear to be models for healthy tissues in longleaf pines. They contain high numbers of large starch grains and have active nuclei. Only one root died and the proportion of roots with excess tannins was much lower compared to mature trees. Roots from the adult trees reflect a number of processes that appear to be minimal in the saplings. For example, the high numbers of dead roots in adult trees might imply a much greater turnover rate relative to the young saplings.

Thus, studies involving root metabolism interactions with silvicultural treatments should take advantage of sapling root vigor as a standard reference point for comparison. The variable, starch use, was particularly sensitive for comparing roots on different saplings. Although we did not measure the sink for the glucose that results from starch hydrolysis, large quantities of simple carbohydrates would be needed to sustain growth of the root system and for rapid top growth (1.0 to 2.0 m per year) (Allen and Scarbrough 1969). This sensitivity can also confound data interpretation as they related to site productivity and silvicultural regime, and underscores the necessity of further comparative studies.

On the other hand, the dramatically lower starch concentration in mature tree roots may imply a degree of stress and unthriftiness. This is supported by our data on the high amount of infected roots present on this site (Otrosina and others 2000). Assessment of root vigor and health by application of these standard histological procedures will contribute to evaluation of various silvicultural treatments and their effects on forest health and productivity such as being conducted by Haywood (2000).

CONCLUSION

This study begins to address a void in our knowledge of the histological parameters that can be useful in evaluating effects of silvicultural treatments in longleaf pine and other pine species. Further comparative studies are needed over a wide range of sites, silvicultural treatments, age classes, and pathological conditions. Once baselines and key variables are established, these techniques will permit forest health assessment over wide geographic areas.

ACKNOWLEDGMENTS

The authors thank the Savannah River Forest Station and the Department of Energy, Savannah River Site, New Ellenton, SC, for funding portions of this study.

LITERATURE CITED

Allen, R.M.; R.M. Scarbrough. 1969. Development of a year's height growth in longleaf pine saplings. SO - 45 Research Paper: U.S.Department of Agriculture, Forest Service. 13 p.

Derr, H.J. 1966. Longleaf X slash hybrids at age 7: survival, growth, and disease susceptibility. Journal of Forestry: 236-230.

Hass, E. 1980. Fifty diagnostic special stains for surgical pathology. Los Angles, CA: All-Type Editorial. 86 p.

Haywood, J.D. 2000. Mulch and hexazinone herbicide shorten the time longleaf pine seedlings are in the grass stage and increase height growth. New Forests 19: 279-290.

Horobin, R.W.; J.D. Bancroft. 1998. Troubleshooting Histology Stains. New York: Churchill Livingstone. 266 p.

Mann, W.F. Jr. 1969. At last - longleaf pine can be planted successfully. Forest Farmer 28: 6-7, 18-19.

Otrosina, W.J.; Walkinshaw, C.H.; Sung, S.S.; Sullivan, B.T. 2000. Root disease and insects associated with longleaf pine mortality may be induced by current and edaphic silvicultural conditions. Phytopathology 90(6): S127-128 (Abstr).

Preece, A. 1972. A manual for histologic technicians (3rd ed.) Boston: Little, Brown, and Co. 263 p.

Sass, J.E. 1951. Botanical microtechnique. 2d ed. Ames, IA: Iowa State College Press. 228 p.

Fire

Moderator:

DAVID VAN LEAR
Clemson University

DELAYED PRESCRIBED BURNING IN A SEEDLING AND SAPLING LONGLEAF PINE PLANTATION IN LOUISIANA

James D. Haywood[1]

Abstract—To examine the effects of delaying prescribed burning for several years, I initiated five treatments in a 5- to 6-year-old longleaf pine stand: a check of no control; biennial hardwood control by directed chemical application; and biennial burning in either early March, May, or July. After the initial burns, longleaf pine survival decreased from 82 percent in February 1999 to 67 percent in November 2000. Mortality was highest among the smallest pine trees. Total pine heights in November 2000, adjusted for initial heights in February 1999, averaged 11.9, 11.5, 10.9, 11.4, and 11.3 ft on the five treatments, respectively. Total height was significantly greater on the check treatment than the average of the other four treatments, and March burning had the most adverse effect on height growth.

INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) forests once constituted a major ecosystem in the Southern United States stretching from southeastern Virginia to central Florida and west into east Texas (Outcalt and Sheffield 1996). These forests covered a wide range of site conditions from wet pine flatwoods to dry mountain slopes, but intensive exploitation reduced the extent of old-growth longleaf forests to only 3.2 million ac by 1993.

The continued loss of longleaf pine forests has endangered or threatened nearly 200 associated taxa of vascular plants and several vertebrate species (Brockway and others 1998). Protecting the remaining longleaf pine forests and restoring longleaf pine plant communities within their historical ranges are paramount in saving these threatened species from extinction. The reintroduction of longleaf pine generally involves the use of fire for preparing sites for regeneration, and prescribed burning usually continues from seedling establishment through stand maturity (Boyer 1993, Croker and Boyer 1975, Haywood and Grelen 2000, Wahlenberg 1946).

Newly established longleaf seedlings may develop little aboveground for several years as the root system develops (Harlow and Harrar 1969). The bunch of needles at the surface resembles a clump of grass, hence the term grass stage describes the juvenile period of growth. Once the seedlings have developed a root collar of about 1 in., they are able to emerge from the grass stage.

Because aboveground growth of longleaf seedlings is slow in newly established stands, a burning program helps keep competing woody vegetation from overtopping and crowding the longleaf pine regeneration, removes dead grass that smothers young seedlings, and reduces the occurrence of brown-spot needle blight caused by *Mycosphaerella dearnessii* Barr. (Croker and Boyer 1975, Wahlenberg 1946).

However, prescribed burns are not always executed on schedule because of adverse weather conditions and lack of resources. A delay of several years can allow fine fuels to accumulate, and this accumulation increases the likelihood of more intense burns when the burning program begins. Delayed burning is, therefore, more likely to destroy seedling and sapling longleaf pines than if fuel loads are kept in check. If fire is not used or is delayed too long, competing woody plants [especially loblolly pine (*P. taeda* L.)] have to be controlled by cutting or directed applications of herbicides on many sites (Haywood 2000). If not, a mixed overstory will eventually develop of loblolly, longleaf, and hardwoods, with a midstory of trees and shrubs that shades out most of the understory vegetation (Haywood and Grelen 2000). To examine the effects of delaying prescribed burning for several years, I initiated this study in a seedling and sapling-size stand of planted longleaf pine.

STUDY AREA

The study area is on the Longleaf Tract, Palustris Experimental Forest, Kisatchie National Forest, in central Louisiana about 19 mi south-southwest of Alexandria (approximate longitude 92°30' W., latitude 31° N.) at an average elevation of 170 ft. Harms (1996) classes the naturally infertile Beauregard-Malbis silt-loam soil complex as a wet pine site because it is seasonally wet during winter although often droughty during summer. Haywood (2000) describes the soils and subtropical climate.

The original forest stand was clearcut harvested in the mid-1980s. The unmerchantable stems and new growth were sheared and windrowed in 1991. A low cover of herbaceous and scattered woody vegetation developed after windrowing, and it was rotary mowed in July and August 1992.

[1] Research Forester, Southern Research Station, Alexandria Forestry Center, 2500 Shreveport Highway, Pineville, LA 71360-5500.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

METHODS

Study Establishment

Initially, I established research plots in a randomized complete block split-plot design and removed them in December 1992 (Haywood 2000). Each of the 15 whole plots (5 blocks by 3 main plot treatments) measured 84 by 84 ft (0.16 ac) and contained 14 rows of 14 seedlings arranged in 6-by-6 ft spacing. I divided the center 100 seedlings equally into 2 subplots, and randomly assigned year-of-planting to each of the 50-seedling subplots. One subplot was planted in February 1993 and the other subplot was planted in January 1994. For each year-of-planting, I used the same Mississippi seed source. My crew hand planted the 42-week-old container longleaf seedlings with a punch of the correct size for the root plug. In both years the soil was wet, and we encountered no planting problems.

To determine the effects of herbaceous vegetation management practices on growth of newly planted longleaf pine seedlings, I assigned 3 treatments to the 15 whole plots (Haywood 2000). These treatments were (1) no herbaceous plant control after planting, (2) two annual applications of hexazinone herbicide [3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione], and (3) mulching. Despite treatment, on all plots hardwood and loblolly pine brush overtopped and crowded the planted longleaf seedlings. We manually severed the brush in 1997 and sprayed the new growth with triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) herbicide in 1998. The most commonly treated plant was waxmyrtle (Myrica cerifera L.).

New Study Design

After completing the initial vegetation management research and reporting the findings (Haywood 2000), I initiated this new phase of research to address delayed prescribed burning. This shift was possible because in the original design, the block, seedling age (subplot), and treatment-by-age interaction effects were not significant (a = 0.05). Therefore, I reconfigured the design, and the three original treatments—check, herbicide application, and mulching—became the blocks. Blocking was justified because of significant differences in longleaf pine total height among the original treatments (Haywood 2000).

I randomly assigned five treatments within the three blocks, or replicates (Steel and Torrie 1980). In the first (check) there was no more woody plant control after 1998. In the second (herbicide) beginning in 1999 there was biennial control of woody vegetation over 2 ft tall with a directed application of herbicide (triclopyr) in May; we did not treat blackberry (*Rubus* spp.) and woody vines. In the third, fourth, and fifth treatments, I conducted biennial burning in early March, May, or July, respectively.

Confirmation of the New Study Design

I analyzed pretreatment survival and tree height data taken in February 1999 using the original analysis of variance for a split-plot randomized complete block design model (Steel and Torrie 1980). However, this time I used the new treatments (check, herbicide, March burn, May burn, and July burn) as the main plot effects (table 1). I included tree age and treatment-by-age interaction terms in the analysis, and there were no significant age effects or treatment-by-age interactions in the pretreatment analyses (a = 0.05). Thus, the plots were sufficiently uniform to continue with the new research, and I ignored the age of seedlings in future analyses.

Burning Samples and Technique

Before setting fires, I collected a combustible fine fuel sample on five randomly located 2.4-ft^2 fuel-monitoring plots. I again collected fuel samples 1 week after the burns to determine fuel consumption on a dry-weight basis. I calculated Byram's fire intensity for each burn (Haywood 1995).

All burns were strip-head fires set with drip torches and were monitored to determine their intensity (Haywood 1995). First, we set a backfire along the downwind side of the plot. After the line was secure, we lit the strips about 24 ft apart and allowed them to burn together.

Measurements

Before initiating new treatments, I measured longleaf pine total height in February 1999 to use as a covariate in future analyses. I measured posttreatment total height and diameter at breast height in October 1999 and November 2000, 4 to 7 and 17 to 20 months after the initial set of treatments, respectively.

Data Analysis

The model was a randomized complete block design with three blocks as replicates (Steel and Torrie 1980), and I analyzed two groups of longleaf pine—all pine trees or just those out of the grass stage (pines over 0.4 ft tall). In this first analysis, dependent variables were pretreatment pine survival and total height measured in February 1999 and pretreatment survival and heights adjusted for mortality through November 2000. If I found significant treatment differences (a = 0.05), I used Duncan's Multiple Range Tests to determine mean separations.

In subsequent analyses of posttreatment total height and diameter measurements, I used the pretreatment heights as a covariate in the study design (Steel and Torrie 1980). I did not use pretreatment diameters as covariates because not all trees were at least 4.5 ft tall in February 1999.

I used linear contrasts to determine differences among treatments to address several hypotheses associated with delayed burning based partly on Haywood and Grelen (2000). First, suspension of woody plant control will eventually be detrimental to longleaf pine trees: treatment 1 versus treatments 2 through 5. Second, biennial burning and woody plant control with herbicides will have similar effects: treatment 2 versus treatments 3 through 5. Third, burning in May will have similar growth effects as burning in March or July: treatment 4 versus treatments 3 and 5, and fourth, March and July burning will have similar effects: treatment 3 versus treatment 5.

Table 1—Confirmation of the new study design; the 5- and 6-year-old longleaf pine were measured in February 1999 before the initiation of treatments[a]

	All longleaf pine			Longleaf out of the grass stage		
Treatment effects	Survival	Height	Disease	Pines out of grass stage	Height	Disease
	Pct	*Ft*	- - - - - - *Percent*	- - - - - -	*Ft*	*Pct*
Treatments						
1. Check	86	6.3	10	82	6.6	10
2. Herbicide	86	5.0	12	79	5.3	11
3. March burn	79	5.5	7	74	5.8	6
4. May burn	83	5.3	11	79	5.6	11
5. July burn	84	4.3	15	76	4.6	16
Prob>F-value	.205	.388	.221	.243	.405	.104
Age						
5-year-old trees	83	4.9	11	77	5.2	10
6-year-old trees	84	5.7	11	79	6.0	11
Prob>F-value	.786	.212	.937	.730	.190	.497
Treatment-by-age interactions						
5-year-old trees						
1. Check	87	5.7	11	83	6.0	10
2. Herbicide	85	4.8	14	79	5.1	12
3. March burn	82	5.1	7	76	5.5	7
4. May burn	82	4.5	10	76	4.8	10
5. July burn	79	4.4	13	74	4.7	12
6-year-old trees						
1. Check	85	7.0	9	81	7.2	9
2. Herbicide	87	5.2	11	80	5.6	9
3. March burn	76	6.0	7	73	6.2	6
4. May burn	85	6.1	12	81	6.3	11
5. July burn	88	4.2	18	79	4.6	20
Prob>F-value	.205	.894	.782	.655	.934	.523

[a] There were no significant treatment or age differences or treatment-by-age interactions before treatments began (a = 0.05).

RESULTS

Burning Effects

I conducted the first set of burns in a 6-year-old grass-dominated rough. Grasses dominated the rough because woody competitors were controlled on all plots before the study began (table 2). Fire intensities ranged from 84 to 199 British thermal units (Btu) per foot, which were well above the recommended maximum intensity of 50 Btus per foot (Haywood 1995).

Treatment Effects

Tree mortality was low on the check and herbicide treated plots, decreasing on average from 86 percent in February 1999 to 81 percent in November 2000 (table 3). The dead longleaf pines averaged < 1 ft tall; so, initial heights of living trees increased from 5.7 to 6.1 ft once I dropped dead trees from the data set.

Prescribed burning, regardless of date, reduced longleaf pine survival, which decreased from an average of 82 percent in February 1999 to an average of 67 percent in November 2000 on the three burned treatments (table 3). The dead trees averaged < 2 ft tall. Thus before burning, the longleaf pines averaged 5.0 ft tall, and after I dropped these dead trees from the data set, the surviving pines averaged 5.9 ft tall in the pretreatment measurement (table 3).

In February 1999, percentage of pines out of the grass stage (pines over 0.4 ft tall) averaged 96 percent and ranged from 94 percent on the March-burn plots to 97 percent on the check and herbicide plots (table 3). Although these were the tallest trees, fire had the same adverse

Table 2—Parameters and intensities for the three 1999 prescribed burns conducted in a 6-year-old grass rough in 1999

Treatments	Burning date	Diurnal temperature range	Wind speed	Average fuel load[a]	Range in fire intensity	Average fire intensity[b]
		°F	*Mph*	*Lbs/ac*	- - - - *Btu per foot* - - - -	
March burn	March 2	56 – 73	4	3,305	92 – 124	111
May burn	May 14	56 – 86	2	5,360	84 – 109	99
July burn	July 8	70 – 91	3	3,908	116 – 199	170

[a] Oven-dried weights.
[b] Average fire intensities were from two to over three times the recommended maximum intensity of 50 Btus per foot (Haywood 1995).

effect on survival as for all pines partly because longleaf pines are still highly vulnerable to fire damage and mortality until the seedlings are 4 to 6 ft tall (Bruce 1951). Longleaf pines out of the grass stage averaged 5.3 ft tall before burning, and after I dropped the dead trees from the data set, the remaining pines averaged 6.0 ft tall on the three burned treatments.

In October 1999 and 4 to 7 months after treatment, height of all longleaf pines was significantly greater on the checks (8.8 ft) than the average for the other four treatments (8.3 ft), and height was significantly greater on the herbicide plots (8.5 ft) than the average for the three burned treatments (8.2 ft) (table 3). Tree height was significantly greater on the July-burn plots than on the March-burn plots. Diameter of longleaf pines did not significantly differ among treatments, although diameter at breast height on the herbicide plots (1.5 in.) was greater than the average for the three burned treatments (1.4 in.) at probability > F-value (P) = 0.07. I found a similar pattern of treatment responses for longleaf pines out of the grass stage.

In November 2000 and 17 to 20 months after treatment, height of all longleaf pines was still significantly greater on the checks (11.9 ft) than the average for the other four treatments (11.3 ft) (table 3). None of the other treatment contrasts were significant, although the July-burn trees (11.5 ft) were taller than the March-burn trees (10.9 ft) at P = 0.07. Diameter did not significantly differ among treatments, although the checks (2.0 in.) had a greater diameter at breast height than the average for the other four treatments (1.9 in.) at P = 0.06. I found a similar pattern of treatment responses for longleaf pines out of the grass stage.

DISCUSSION

The rapidity that loblolly pine and hardwood brush develops in new longleaf pine plantations is a serious problem that managers must address either with fire, herbicides, or a combination of treatments (Haywood and Grelen 2000). However, neither herbicides nor fire are panaceas for managing longleaf pine stands. Fire can destroy seedlings in and emerging from the grass stage, and later the use of fire can adversely affect stand growth and yield (Boyer and Miller 1994, Bruce 1951, Harlow and Harrar 1969, Wahlenberg 1946). Misapplied herbicides can injure desirable plants and contaminate soil and water resources.

Overall, the fire intensities for the three 1999 burns were unacceptably high partly because the delay in burning allowed fine fuels to accumulate over the previous 6 years. Still, delaying the first burn also allowed many of the longleaf seedlings to reach a stature where they could better tolerate heat injury (Bruce 1951, Greene and Shilling 1987, Haywood 1995). Therefore, mortality was mostly among the smallest seedlings that were of little consequence toward future stand development.

Originally we considered that delayed burning would avoid the documented, detrimental effect that repeated March burning has on longleaf pine seedling and sapling growth (Haywood and Grelen 2000). Although mortality was largely among the smallest pine trees, the untreated checks still had greater height growth than the treated plots, and March was still the most detrimental time to burn. This suggests that the application of fire or herbicide had sublethal effects on the trees that were not as obvious as the heat-related death of the smallest trees.

Longleaf pine remains very susceptible to heat-related injury until the seedlings are about 6 ft tall (Bruce 1951). Trees on the burned plots averaged about 6 ft tall at the beginning of the study, and probably most did not have the stature to avoid injury especially at the high fire intensities experienced (table 2). Also, a larger proportion of a smaller tree is exposed to a misapplication of directed herbicide than is a larger tree, and smaller trees are less obvious and therefore more often accidentally sprayed than larger trees. Regardless, neither delaying the first burn nor application of herbicide benefited these 5- and 6-year-old longleaf pines.

Table 3—Survival and growth responses of longleaf pine to the initial series of treatments under the new study design[a]

	Pretreatment		Post-treatment					
	Pines surviving in February 1999				October 1999		November 2000	
Treatment effects	Living pines	Covariate height	Survival	Covariate height	LSM[b] height	LSM D.b.h.	LSM height	LSM D.b.h.
	Percent	*Ft*	*Percent*	- - - - - - - *Ft* - - - - - -		*In.*	*Ft*	*In.*
All longleaf								
1. Check	86	6.3	81a[c]	6.8	8.8	1.47	11.9	2.01
2. Herbicide	86	5.0	81a	5.3	8.5	1.46	11.5	1.97
3. March burn	79	5.5	69b	6.1	7.7	1.30	10.9	1.85
4. May burn	83	5.3	67b	6.3	8.3	1.35	11.4	1.92
5. July burn	84	4.3	66b	5.2	8.6	1.38	11.3	1.91
Prob>F-value	.205	.389	.006	.695	.001	.128	.024	.141
Contrasts[d]								
Trt 1 vs trt 2–5					.002	.106	.012	.067
Trt 2 vs trt 3–5					.026	.064	.106	.159
Trt 4 vs trt 3+5					.217	.895	.217	.371
Trt 3 vs trt 5					.001	.281	.074	.340
Longleaf out of the grass stage								
1. Check	97[e]	6.6	80a[c]	6.8	9.0	1.50	12.1	2.05
2. Herbicide	97	5.3	79a	5.4	8.7	1.49	11.8	2.01
3. March burn	94	5.8	66b	6.4	7.9	1.33	11.2	1.91
4. May burn	96	5.6	66b	6.4	8.5	1.38	11.6	1.96
5. July burn	96	4.6	65b	5.3	8.7	1.41	11.5	1.94
Prob>F-value	.590	.405	.005	.682	.002	.134	.056	.275
Contrasts[d]								
Trt 1 vs trt 2–5					.004	.108	.022	.112
Trt 2 vs trt 3–5					.035	.064	.144	.211
Trt 4 vs trt 3+5					.277	.898	.308	.492
Trt 3 vs trt 5					.001	.308	.215	.633

[a] Seedling age was ignored but the seedlings were in the sixth or seventh growing season after planting when first treated.
[b] LSM = Least-squares means are adjusted to make them the best estimates of what they would have been if all the covariate means had been the same (Steel and Torrie 1980).
[c] By longleaf pine group and for pine survival, means followed by the same letter are not significantly different based on Duncan's Multiple Range Tests (a = 0.05).
[d] The linear contrasts compared (vs) preselected combinations of the preceding treatments (trt), and the Prob>F-value are reported for each contrast.
[e] Percentage of the living pines out of the grass stage when the study began.

LITERATURE CITED

Boyer, William D. 1993. Long-term development of regeneration under longleaf pine seedtree and shelterwood stands. Southern Journal of Applied Forestry. 17(1): 10–15.

Boyer, William D.; Miller, James H. 1994. Effect of burning and brush treatments on nutrient and soil physical properties in young longleaf pine stands. Forest Ecology and Management. 70: 311–318.

Brockway, Dale G.; Outcalt, Kenneth W.; Wilkins, R. Neal. 1998. Restoring longleaf pine wiregrass ecosystems: plant cover, diversity and biomass following low-rate hexazinone application on Florida sandhills. Forest Ecology and Management. 103: 159–175.

Bruce, David. 1951. Fire, site, and longleaf height growth. Journal of Forestry. 49(1): 25–27.

Croker, Thomas C., Jr.; Boyer, William D. 1975. Regenerating longleaf pine naturally. Res. Pap. SO–105. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 21 p.

Greene, Thomas A.; Shilling, Charles L. 1987. Predicting girdling probability for pine and hardwood saplings in low-intensity backfires. Forest Science. 33(4): 1010–1021.

Harlow, William M.; Harrar, Ellwood S. 1969. Textbook of dendrology. 5th ed. New York: McGraw-Hill Book Company. 512 p.

Harms, William R. 1996. An old-growth definition for wet pine forests, woodlands, and savannas. Gen. Tech. Rep. SRS–2. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 7 p.

Haywood, James D. 1995. Prescribed burning and hexazinone herbicide as release treatments in a sapling hardwood-loblolly pine stand. New Forests. 10: 39–53.

Haywood, James D. 2000. Mulch and hexazinone herbicide shorten the time longleaf pine seedlings are in the grass stage and increase height growth. New Forests. 19: 279–290.

Haywood, James D.; Grelen, Harold A. 2000. Twenty years of prescribed burning influence the development of direct-seeded longleaf pine on a wet pine site in Louisiana. Southern Journal of Applied Forestry. 24(2): 86–92.

Outcalt, Kenneth W.; Sheffield, Raymond M. 1996. The longleaf pine forest: trends and current conditions. Resour. Bull. SRS–9. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 23 p.

Steel, Robert G.D.; Torrie, James H. 1980. Principles and procedures of statistics. 2d ed. New York: McGraw-Hill Book Company. 633 p.

Wahlenberg, W.G. 1946. Longleaf pine its use, ecology, regeneration, protection, growth, and management. Washington, DC: Charles Lathrop Pack Forestry Foundation; U.S. Department of Agriculture, Forest Service. 429 p.

UNDERSTORY HERBICIDE AS A TREATMENT FOR REDUCING HAZARDOUS FUELS AND EXTREME FIRE BEHAVIOR IN SLASH PINE PLANTATIONS

Patrick Brose and Dale Wade[1]

Abstract—The 1998 wildfires in Florida sparked a serious debate about the accumulation of hazardous forest fuels and the merits of prescribed fire and alternatives for mitigating that problem. One such alternative is application of understory herbicides and anecdotal evidence suggests they may either exacerbate or lessen the fuel accumulation problem. In 1998, a study was initiated in northern Florida to document changes in fuel characteristics in slash pine (*Pinus elliottii*) plantations treated with a mid-rotation understory herbicide and model their potential impacts on fire behavior. Field data showed unmanaged stands contained the highest loadings of understory fuels and in the first year after herbicide treatment, fuel loading did not change. In subsequent years, fuel loading rapidly decreased and remained low. Potential fire behavior, as predicted by BEHAVE, followed this fuel accumulation trend in that catastrophic stand-replacing fires were predicted for unmanaged and recently herbicided stands, and low-intensity surface fires for stands that had been herbicided several years prior.

INTRODUCTION

In 1998, Florida experienced one of its most active wildfire seasons ever (Karels 1998). From mid-May to mid-July, over 2000 wildfires occurred in central and northern Florida. Over 500,000 acres of forest burned, most of them by high-intensity/high-severity, stand-replacing fires. Over 10,000 firefighters from 49 states fought the fires. Property losses included the destruction of, or damage to, 370 businesses and residences. Commercial timber losses exceeded $350 million, suppression costs topped $100 million, and estimated tourism losses of nearly $140 million all contributed to the total estimated cost of $622 to $880 million (Mercer et al. 2000). The magnitude and severity of the wildfires prompted several land management agencies, including the USDA Forest Service and the USDI Biological Resources Division, to combine resources to study the ecological and economic impacts of the wildfires on Florida's forest ecosystems. One facet of the USDA/USDI study addressed the issue of hazardous fuel reduction in commercial pine stands and in the urban/wildland interface before a wildfire occurs.

Dormant-season prescription fire every 4 to 5 years has been the method of choice to control the buildup of hazardous fuels throughout the southern United States (Pyne and others 1996). The frequent use of fire is necessary because redevelopment of the rough is rapid with fire hazard returning to its preburn level in less than 5 years on most sites (Davis and Cooper 1963). In the past several decades, however, constraints have been placed on this practice because of smoke management concerns, liability issues, and misconceptions about the ecological ramifications of fire among the region's sizeable population of out-of-state retirees (Wade 1993).

The continuing need for hazardous fuel reduction and the social limitations of prescription fire have prompted interest in developing other strategies for managing hazardous fuels. One possible alternative is the herbicides that are often used as a mid-rotation treatment in commercial pine plantations to boost growth and reduce future site preparation costs (Oppenheimer et al. 1989). Herbicides reduce height, percent cover, and/or loading of the highly flammable shrub layer although the degree and longevity of hazardous fuel control is not well defined.

This study is two-phased; a detailed fuels inventory followed by computer simulations based on the fuels data. The objective was to compare fire behavior (flame length and rate-of-spread) that probably would occur in slash pine plantations treated with herbicide at five different times after treatment (age-of-rough). Because the 1998 wildfires occurred during a severe drought, fire behavior was simulated for each age-of-rough under June 1998 weather conditions.

METHODS

The fuels data for this study was collected during winter 1998-1999 on forest industry (Georgia-Pacific and ITT Rayonier) land located between Lake Butler and Starke in Bradford and Union counties in the Coastal Plain Physiographic Province of northern Florida. Fifteen stands varying from 4 to 35 acres in size were chosen based on the age of rough, i.e., number of years (1, 2, 3, 6, or untreated) since the herbicide treatment. The "untreated" age class indicated no herbicide spraying since planting and included stands that had been unmanaged for 17 years.

[1]Research Silviculturist, USDA Forest Service, Northeastern Research Station, Irvine, PA; Fire Scientist, USDA Forest Service, Southern Research Station, Athens, GA, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

All of these stands were slash pine plantations grown on a pulpwood rotation of about 30 years. They were 17 years old with an average stand diameter of 8.5 inches and contained 110 – 140 ft^2 of basal area per acre.

In each stand, understory fuel characteristics (cover, height, and loading by size class) were collected as inputs to BEHAVE to build custom fuel models. Percent cover and height were determined for all stands using line transects. Near the center of each stand, six 215ft-long transects were systematically located parallel to one another 80-ft apart. The vegetation was sampled along each transect at 16-ft intervals by holding a 8-ft tall range pole perpendicular to the ground and recording each plant species touching the range pole and the height of the tallest plant. Percent cover and height to the nearest 0.5 ft were determined for five categories; grass, open space, saw palmetto, small shrub, and tall shrub. Grass included all graminoid species, i.e., *Andropogon* spp., *Aristata* spp., and *Panicum* spp., while saw palmetto was species specific. Tall shrub was primarily gallberry but also included all other woody shrubs ≥ 0.5 ft tall while small shrub included all < 0.5 ft tall, e.g., blueberry (*Vaccinium* spp.) and runner oak (*Quercus pumila*). Open space represented areas devoid of vegetation but usually blanketed by pine litter. Because sampling was done in January and February, no forbs were found.

The clip-bag-dry method was used to determine loadings of shrub and litter fuels. In this method, six 3-ft x 3-ft quadrats were located on a 100-ft x 100-ft grid near the center of the stand. Quadrats were delineated by a sampling frame and all vegetation, living and dead, within the frame and between 0.1 and 10.0 ft tall was designated as either grass or shrub fuels and clipped, bagged, and dried. All plant material on or in the forest floor (O_i and O_e horizons) was likewise collected and designated as litter fuels.

Fuel samples were dried at 195°F to a constant weight in a wood-drying oven then separated by type (grasses, pine litter including dead downed woody material, and shrubs) and by diameter size class (<0.25 inches and 0.25 to 1.00 inches). These size classes correspond to the time-lag fuel classes of 1-hr and 10-hr, respectively (Fosberg 1970). Fuels >1.00 inches in diameter were virtually nonexistent and ignored for the purposes of this study. After separation, fuels were weighed to the nearest 0.1 ounces on an electronic scale.

All fuels data were used in the NEWMDL program (Burgan and Rothermel 1984) of BEHAVE to create a custom fuel model for each age-of-rough. Physical and chemical characteristics of the palmetto-gallberry fuel complex were obtained from Hough and Albini (1978).

Custom fuel models were used in conjunction with landform and weather data in the SITE module of the FIRE1 program to develop treatment/age-of-rough specific fire behavior estimates (Andrews 1986). The Osceola National Forest provided weather data for June 1998. Cloud cover, ambient air temperature, relative humidity, 20-ft windspeed, precipitation, and fuel moistures were recorded daily at 1300 hours and averaged for the entire month. Each simulation was of a summer fire (June 15th) burning under drought weather conditions. Outputs were flame length (ft) and rate-of-spread (ft/min) for a head fire for each treatment/age-of-rough combination.

STATISTICAL ANALYSIS

Analysis of variance with Student-Newman-Kuels mean separation test was used to compare differences for cover, height, and loading of fuel types and sizes between the different ages-of-rough (SAS Institute Inc. 1993). In all tests $\alpha = 0.05$ and data were transformed as needed to correct for unequal variances and non-normality of residual values. Flame length outputs from each simulation were compared to fire characteristic – suppression charts (Andrews and Rothermel 1982) to rate the difficulty of controlling a wildfire burning under drought and normal conditions.

Table 1—Fuel characteristics (mean ± 1 s.e.) for rough age 1, 2, 3, 6, and 17 years

Fuel Characteristic/Type		Age of Rough (years)			
Cover (percent)	Untreated[a]	1	2	3	6
Grass	0±0C[b]d[c]	0.9±0.4Cd	6.7±0.5Ad	4.9±0.4Bc	0.9±0.2Cd
Litter	18.7±1.7Cb	20.0±2.0Cb	34.2±1.8Bb	69.8±4.8Aa	69.3±4.2Aa
Saw palmetto	6.7±0.8Cc	3.1±0.2Dc	9.3±0.2Bc	0.2±0.2Ed	19.6±0.3Ab
Short Shrub	1.8±2.1Ad	0.4±0.6Ad	0.2±0.1Ae	0.1±0.1Ad	0.2±0.2Ad
Tall Shrub	72.9±7.5Aa	75.6±7.0Aa	49.8±5.3Ba	25.3±3.2Cb	10.2±0.8Dc
Height (ft)	5.0±0.7A	4.6±0.5A	3.6±0.4B	1.6±0.3C	3.6±0.5B
Loading (tons/ac)					
Grass	0±0Bc	0.1±0.1Bc	0.3±0.2Ab	0.1±0.1Bb	0.1±0.1Bc
Litter, 1-hr	4.7±0.4Ca	5.6±0.6Ba	7.5±0.7Aa	7.5±0.8Aa	5.0±1.1BCa
Litter, 10-hr	0.6±0.7Ac	0.4±0.3Ac	0.9±1.1Ab	0.6±1.1Ab	0.8±0.5Abc
Shrub, 1-hr	3.5±0.6Aa	3.5±0.6Ab	1.1±0.3Bb	0.3±0.3Cb	1.6±0.5Bb
Shrub, 10-hr	2.0±0.5Ab	2.0±0.5Ab	0.6±0.6Bb	0.1±0.2Cb	0.9±0.6Bbc

a—Untreated stands = rough age 17 years.

b—Means followed by different uppercase letters are different within that row (μ = 0.05).

c—Means followed by different lowercase letters are different within that fuel characteristic/type (μ = 0.05).

Table 2—Characteristics[a] of the custom herbicide fuel models for rough age 1, 2, 3, 6, and 17 years

Treatment Age-of-rough (years)	Fuel Loading[b] 1-hr (tons/ac)	10-hr (tons/ac)	Live Woody (tons/ac)	Height (ft)	Surface-to - Volume ratio (in^2/in^3)	Moisture of Extinction (%)
Untreated[c]	9.47	2.54	2.96	0.69	328	35
1	8.54	2.06	0.18	0.08	326	34
2	8.37	1.25	0.13	0.06	294	40
3	7.87	0.72	0.07	0.03	282	41
6	5.32	0.98	0.81	0.04	292	32

a - Other characteristics, i.e., live woody S/V ratio (359), and heat content (8436 BTU/lb), were averages from Hough and Albini (1978) and kept the same for all fuel models.

b - Live herbaceous fuel load was 0.05 tons/ac for all fuel models. No 100-hr fuels were included in any of the fuel models because of their scarcity.

c - Untreated stand with a rough age = 17 years.

RESULTS

Before spraying, gallberry dominated the forest floor in these stands but afterwards this shrub was replaced by open space blanketed with pine litter (table 1). Saw palmetto was lacking in this treatment because of intensive site preparation when the plantations were established. Initially, height reduction was unchanged as the dead shrubs remained standing for 1-2 years. By age 3, the dead shrubs had fallen, creating rather open stands. Some shrub growth was detected in year 5 but this was due to skips in the spraying that allowed some shrubs to survive. Fuel loadings were distributed in similar fashion to the shrub height data. The greatest loadings were found in the untreated stands and were usually dominated by the 1-hr fuels in the litter and shrub fuel types. These decreased through time and shifted from the shrub layer to the forest floor.

Custom fuel models were created from these fuels data (table 2) and used in conjunction with weather and land-form data (table 3) to produce fire behavior outputs for each age of rough.

The flame length predictions were initially unchanged following treatment but then declined dramatically with time (table 4). Under drought conditions in the untreated stands, predicted flame length was 17 ft and declined only slightly by age 1 following herbicide treatment to 16 ft. However, at age 2 flame length dropped precipitously to 8 ft and continued downward to 1.3 ft at age 3 before slightly rebounding to 3.3 ft at age 5. Flame length estimates for normal weather conditions followed this same pattern but were reduced by about 30% relative to drought conditions.

Rate-of-spread predictions followed a similar pattern to flame length estimations (table 4). For drought conditions, it was initially high (49 ft/min) and increased slightly at age 1 to 59 ft/min. From that point, rate-of-spread dropped rapidly to 10 ft/min at age 2, 2.3 ft/min at age 3, and 5.6/min at age 5. Normal weather conditions reduced all rate-of-spread estimates by another 45-60%.

Table 3—Drought, normal weather, and environmental conditions[a] used in the fire simulations

Characteristic	Drought	Normal
Drought Index (KBDI[b])	731	293
Ambient Air Temperature (°F)	97	84
Relative Humidity (%)	42	65
20-ft Windspeed (mi/hr)	11	7
Cloud Cover (%)	10	40
1-hr fuel moisture (%)	5	15
10-hr fuel moisture (%)	6	13
Live Woody fuel moisture (%)	104	166
Days w/o rain	25	15
30-day rainfall total (in)	2.1	5.2
Slope (%)	0	0
Elevation above sea level (ft)	100	100
Latitude	30°N	30°N

a—Data are from the Osceola National Forest as recorded daily at the Olustee Lookout Tower at 1300 hours during June 1997 (normal) and June 1998 (drought). N = 30 for all characteristics except for the last 5 which are totals or site descriptors.

b—Keetch-Byram Drought Index assesses the combined effect of evapotranspiration and amount of precipitation in producing moisture deficits in the soil (Keetch and Byram 1968) It was developed specifically for southern fire managers and provides a scale from 0 to 800 with 800 representing desert-like conditions.

Table 4—BEHAVE-derived estimates of flame length, rate-of-spread, and control difficulty for wildfires burning under normal and drought conditions in herbicide-treated slash pine plantations at rough age 1, 2, 3, 6, and 17 years.

Weather Condition			Age of Rough (years)		
Fire Characteristic	Untreated[a]	1	2	3	6
Drought					
Flame length (ft)	17.0	16.1	8.0	1.3	3.3
Rate-of-spread (ft/min)	49.0	59.0	10.0	2.3	5.6
Control Difficulty	extreme	extreme	moderate	low	low-moderate
Normal					
Flame length (ft)	12.0	11.4	5.6	1.0	2.3
Rate-of-spread (ft/min)	27.0	33.0	6.0	1.3	2.2
Control Difficulty	extreme	extreme	moderate	low	low

a - Stand with a rough age = 17 years.

Suppression difficulty of a wildfire varied among age-of-rough but did not vary between drought and normal weather conditions so these parameters were pooled to ease reporting (table 4). In untreated and 1-year-old stands, a wildfire would probably display extreme fire behavior, i.e., torching, crowning, and spotting, making suppression extremely difficult. However, difficulty of wildfire suppression would decrease with time and after year 2 would become quite easy and would likely remain that way through rotation end.

DISCUSSION

In pine flatwood forests, it is the age and development of the rough that determines fire behavior more than any other forest characteristic (Hough and Albini 1978). This study demonstrates the effectiveness and limitations of herbicides as an alternative to prescribed fire for protecting slash pine plantations from stand-replacing wildfires. In the untreated stands, the rough was nearly impenetrable, consisting of almost complete coverage of highly flammable gallberry and saw palmetto that ranged from 3-12 ft tall. A wildfire in such a setting, regardless of whether during drought-enhanced or normal summer weather conditions, would be extremely dangerous, difficult to suppress, and would probably kill all overstory pines.

Herbicide application can reduce this highly flammable rough but it takes time. For the first year after treatment, fuel characteristics changed little. The shrubs were dead but still standing, densely spaced, and retaining fallen needles. Consequently, BEHAVE predicted a wildfire burning under drought conditions would have 17-ft flame length and 49 ft/min rate-of-spread. Under normal weather conditions, these predictions decreased to 12 ft flame length and 27 ft/min rate-of-spread. Difficulty of control would be high to extreme and suppression strategy would be the same as if the fire was burning in an unmanaged stand; necessitating indirect attack and use of natural barriers. Pine mortality from a wildfire in such a scenario would undoubtedly approach 100 percent.

However, fire danger and control difficulties decrease dramatically beginning in year 2 provided that saw palmetto was eradicated during site preparation and herbicide spraying completely covered the stand. Shrub fuels almost disappear and the only 1-hr fuel is the blanket of pine needles above the developing duff layer. The herbicide stands become quite open beginning in year 2. These favorable conditions exist at least until year 6 and quite possibly until final harvest in plantations managed for pulpwood. Under the same weather conditions, fires in such environments would be much less intense than in recently herbicided stands. Direct attack would be relatively safe and easy.

Unfortunately, the decrease in fire intensity may not translate into a decrease in pine mortality. Herbicide-treated stands will have an increased duff accumulation on the forest floor relative to stands that are regularly prescribe-burned. Roots of overstory pines colonize the bottom of this developing duff layer within 3 to 4 years. During drought years this duff layer will be consumed, significantly increasing fire severity. Consequently, a low-intensity fire in a herbicide-treated plantation is likely to root-kill more pines than a higher-intensity fire in a natural stand managed with recurrent prescribed fire because the southern pines have evolved to survive crown scorch approaching 95 percent (Weise et al. 1990; Wade, unpubl. data on file) but cannot tolerate fire damage to their roots (Outcalt and Wade 2000).

Caution must be exercised in interpreting these results and the limitations of BEHAVE must be kept in mind. It is designed to predict average fire behavior at the flaming front of a head fire for a given set of environmental parameters. In this study, we used fuel and weather conditions that we considered typical for early summer in northern Florida and consistent with a near worse-case scenario. Changing location on the fire (flanks or rear) or one or more of the parameters, i.e., windspeed, fuel moisture, or relative humidity, will alter the outputs. Also, outputs are for relative comparison among treatments. Validation of BEHAVE-generated fire predictions to actual fire behavior for these custom fuel models is still needed for the gallberry-saw palmetto fuel complex, especially under drought conditions. Likewise, comparison of actual fire behavior to BEHAVE-generated estimates for the applicable standard fuel models under drought conditions is another topic awaiting research.

CONCLUSIONS

Fire has long been a component of Florida's pine flatwood ecosystems and will undoubtedly continue to be so because of the prevalence of lightning and a growing human population. Because of excellent growing conditions, the rough quickly becomes a hazardous fuel problem that when combined with ignition sources and dry weather can produce extreme fire seasons such as the 1998 season in Florida.

Active fuels management is essential to reduce both size and intensity of wildfires. A passive do-nothing approach to hazardous fuel loadings will result in catastrophic wildfires and exacerbate damage and control difficulties. Herbicide application can be used as an alternative to prescribed fire to control understory development but the forest manager must be aware of this technique's strengths and weaknesses. A single treatment does provide for a long-term reduction of the rough but does not provide immediate fire protection, many of the other benefits of fire, e.g. duff reduction, heat scarification of seeds, nutrient cycling, necessary to maintain the health of natural ecosystems, and may make pines susceptible to root mortality during drought-year fires.

ACKNOWLEDGMENTS

The authors express their gratitude to the many individuals that helped on various phases of this study. We thank Wayne Burns, Greg Driskell, Glen Harris, Steve Miller, and Ken Owens for granting us access to their lands, making their forest management records available to us, and helping us locate suitable study stands. We also thank Dave Combs, Helen Mohr, and Jimmy Rickard for their labor collecting and processing fuels data. Finally, we thank Ken Outcalt and David Van Lear for their timely reviews of the manuscript and their helpful comments to improve it. Funding for this research was provided by the Joint Fire Science Program.

REFERENCES

Andrews, P.L. 1986. BEHAVE: Fire prediction and fuel modeling system – Burn subsystem, Part 1. USDA For. Serv. Gen. Tech. Rep. INT-194.

Andrews, P.L.; Rothermel, R.C. 1982. Charts for interpreting wildland fire behavior characteristics. USDA For. Serv. Gen. Tech. Rep. INT-131.

Burgan, R.E.; Rothermel, R.C. 1984. BEHAVE: Fire prediction and fuel modeling system - fuel subsystem. USDA For. Serv. Res. Pap. INT-167.

Davis, L.S.; Cooper, R.W. 1963. How prescribed burning affects wildfire occurrence. Journal Forestry 61(12): 915-917.

Fosberg, M.A. 1970. Drying rates of wood below fiber saturation. Forest Science 16: 57-63.

Hough, W.A.; Albini, F.A. 1978. Predicting fire behavior in palmetto-gallberry fuel complexes. Res. Pap. SE-174. Asheville, NC: U.S. Department of Agricuture, Forest Service, Southeastern Forest Experiment Station. 44p.

Karels, J. 1998. Florida's 1998 wildfire season in review. Florida Division of Forestry internal report.

Keetch, J.J.; Byram, G.M. 1968. A drought index for forest fire control. USDA For. Serv. Res. Pap. SE-38. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 32p.

Mercer, D.E.; Pye, J.M.; Prestemon, J.P.; Butry, D.T.; Holmes, T.P. 2000. Final report: Economic consequences of catastrophic wildfires: Assessing the effectiveness of fuel reduction programs for reducing the economic impacts of catastrophic forest fire events. 66 p. Available on the web at http://flame.fl-dof.com/joint_fire_sciences/index.html.

NOAA. 2000. Climatic Data for 1895 to 2000. Available on the web at http://noaa.ncdc.gov.

Oppenheimer, M.J.; Shiver, B.D.; Rheney, J.W. 1989. Ten-year growth response of midrotation slash pine plantations to control of competing vegetation. Canadian Journal Forest Research 19: 329-334.

Outcalt, K.W.; Wade, D.D. 2000. The value of fuel management in reducing wildfire damage. In Neuenschwander, L.F. and Ryan, K.C. (Tech. Eds.), Proceedings of the Joint Fire Science Conference. 271-275 p.

Pyne, S.J.; Andrews, P.L.; Laven, R.D. 1996. Introduction to Wildland Fire 2nd ed. Wiley and Sons Publishing, New York, NY.

SAS Institute. 1993. User's Guide: Statistics Version 6. SAS Institute Inc. Cary, NC.

Wade, D.D. 1993. Societal influences on prescribed burning. In: Hermann, S. (ed.), Proc. 18th Tall Timbers Fire Ecology Conf., Tall Timbers Res. Stat. 351-355 p.

Weise, D.R.; Wade, D.D.; Johansen, R.W. 1990. Survival and growth of young southern pines after simulated crown scorch. In: 10th Conference on Fire and Forest Meteorology. Soc. Am. For. 161-168 p.

PERIODIC BURNING IN TABLE MOUNTAIN-PITCH PINE STANDS

Russell B. Randles, David H. Van Lear, Thomas A. Waldrop, and Dean M. Simon[1]

Abstract—The effects of multiple, low intensity burns on vegetation and wildlife habitat in Table Mountain (*Pinus pungens* Lamb.)-pitch (*Pinus rigida* Mill.) pine communities were studied in the Blue Ridge Mountains of North Carolina. Treatments consisted of areas burned from one to four times at 3-4 year intervals, and controls which remained unburned. The burns altered stand structure by reducing the density of understory trees and shrubs, which inhibits establishment of many shade intolerant species. Woody fuel loading was not reduced by burning although duff depth decreased. With the exception of the four burn treatment, in which fire intensity was higher, these understory burns proved inadequate to regenerate pine. Fire intensity had a more pronounced effect than burning repetition on vegetative structure and composition, as well as pine regeneration.

INTRODUCTION

Fire in the Southern Appalachians was a frequent visitor prior to European settlement due to both anthropogenic burning as well as natural lightning strikes (Delcourt and others 1998, Pyne and others 1996, Van Lear and Waldrop 1989). Plant communities adapted to a regime of frequent burning; one such forest type in the Appalachians is the Table Mountain-pitch pine community (Della-Bianca 1990, Little and Garrett 1990) This ecosystem has been in decline since fire exclusion policies were initiated in the early twentieth century (Williams and others 1990).

The intensity and frequency of fire necessary to create optimum habitat for sustaining Table Mountain-pitch pine ecosystems has not yet been determined. Some suggest that stand replacement fires may be necessary to create the environment necessary for regeneration (Elliot and others 1999, Turrill 1998), while others suggest more frequent, lower intensity fires may create suitable seedbed habitat (Waldrop and Brose 1998, Van Lear 1999). It is likely that a mix of surface and crown fires burned in Table Mountain-pitch pine stands prior to fire exclusion in the early 1900s.

Fire reduces the cover of species such as mountain laurel (*Kalmia latifolia*) and red maple (*Acer rubrum*) which compete with pines and oaks (Elliot and others 1999). Mountain laurel is an important understory competitor on the xeric ridges where stands of Table Mountain pine occur. Ground layer cover in loblolly and shortleaf pine stands was reduced by an average of 19 percent with a fire interval of three years when compared with intervals of six and nine years and unburned areas (Cain and others 1998). This study also showed a reduction in vertical cover percentage with the frequency of burning.

The purpose of this study was to determine effects of multiple, low-intensity fires on (1) structure and composition of vegetation, (2) fuel loading and arrangement, and (3) regeneration of Table Mountain and pitch pine.

METHODS

Study Areas

The study was located in western North Carolina on the Green River and Thurmond-Chatham gamelands of the North Carolina Wildlife Resources Commission. Forest overstories on the sites were in mixed pine (Table Mountain/Pitch Pine)-hardwood with an understory dominated by mountain laurel.

Plot Layout and Burning

Six to ten sample plots, each 10x20 meters, were installed along the ridge line of each treatment area. There were five treatments: Areas burned 1, 2, 3, and 4 times since 1988, as well as unburned controls. All treatments were burned on a three- to four-year interval. Treatment areas burned two and four times were unreplicated because only one of each of these areas was available. All other burned areas were replicated twice and the control was replicated four times.

[1]Graduate Research Assistant,Clemson University,261 Lehotsky Hall, Clemson, SC 29634; Professor,Clemson University; Research Forester,US Forest Service, Clemson University,233 Lehotsky Hall,Clemson, SC 29634; Wildlife Forester, NC Wildlife Resources Commission, 8676 Will Hudson Road, Lawndale, NC 28090, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Bark char height as an index of fire intensity (Average of max. scorch height after each burn)

	Mean Bark Char Height (m)	
Number of Burns	Thurmond-Chatham	Green River
0	0.00	0.00
1	1.52	1.52
2	N/A	2.29
3	4.06	3.05
4	7.62	N/A

Table 2—Species richness and diversity indices of herbaceous plants for each treatment

Treatment	Species Richnes (# Spp/200 sq. m)		Diversity (Shannon-Weiner)	
Control	12.3	A	.959	A
1 Burn	13.6	A	.875	A
2 Burn	10.2	A	.394	A
3 Burn	12.5	A	.840	A
4 Burn	19.5	B	2.00	A

One source of variation which could neither be accounted for nor controlled was fire intensity. For the most part, burns were of similar intensity; however, fires in the four-burn treatment on Thurmond-Chatham were of considerably higher intensity than the others (Personal Communication. 1999. Dean M. Simon)(table 1). All burns were dormant season burns conducted between January and March.

Vegetative Composition and Structure

Within each sample plot, twenty-one 1 square meter points were sampled along three transects extending the length of the plot. These points were sampled for frequency and percent cover of herbaceous species and *Vaccinium* spp. less than 1 meter in height. Importance value (IV(200)) for each species or species group was calculated using the equation IV(200) = (relative frequency plus relative cover)/2. This value was used to calculate a Shannon-Weiner diversity index (h' = (sum(Pi))ln(Pi))for herbaceous plants at each site.

All trees greater than 2 meters tall within each plot were tallied by species and DBH. It was noted whether they were living or dead. Trees less than 6 centimeters DBH were classified as understory trees, those between 6 and 12 centimeters were midstory, and all greater than 12 centimeters were overstory. These arbitrary classifications were based on the general canopy position of trees in these diameter ranges.

The shrub layer was sampled in two 5x10 meter subplots at the ends of each sample plot. Within these subplots species with multiple woody stems were sampled by number of individuals and number of stems for each individual. *Vaccinium* spp. greater than 1 meter in height were included with the shrub sampling. Width of each crown was measured at the widest point and perpendicular to that point and averaged to obtain crown diameter and percent cover of each individual. Maximum height of the shrub was also recorded for each individual.

Fuel Loading

Within each plot, Brown's planar intersect method (1971, 1974) was applied to three 15.24 meter (50 feet) transects to obtain a fuel loading for surface fuels. One hour fuels (0-.6 centimeters diameter) and ten hour fuels (.6-2.5 centimeters diameter) were counted over the first 2.4 meters (8 feet) of each transect. Both 100 hour (2.5-7.6 centimeters diameter) and 1000 hour (greater than 7.6 centimeters diameter) fuels were counted over the entire length of the transect, recording the diameter of any 1000 hour fuels. The depth of litter (L layer) and duff (F and H layers) was determined at .3, 1.8, 2.7 and 3.6 meters (1, 6, 9 and 12 feet) along each transect.

Height of down woody fuels was recorded at 3.0, 6.1, 9.1, 12.2 and 15.2 meters (10, 20, 30, 40 and 50 feet). This information was entered into the equation derived from Brown (1974) to calculate fuel loading. Vertical fuel height was measured as the mean height of vertical fuels (trees excluded) along each transect at 3.0, 6.1, 9.1, 12.2 and 15.2 meters (10, 20, 30, 40 and 50 feet).

Pine Regeneration

Pine regeneration was sampled concurrently with the 21 points described in the vegetation sampling section. However, the area sampled for pine regeneration at each point was 2x2 meters. Pine seedlings were counted and the height of each was recorded. Pines which had resprouted following a previous fire were measured in a similar manner.

Statistical Analysis

Data were analyzed using an incomplete block design with site as a block and number of burns as a treatment. An analysis of variance was performed sing PROC MIXED in Statistical Analysis Software. In cases where the variance was not uniform a square root transformation was performed to reduce the error (Kuehl 2000). Significance was determined at alpha equal to .05.

RESULTS AND DISCUSSION

Vegetative Structure and Composition

Herbaceous Composition and Diversity—Species richness on the four-burn treatment was significantly higher than the control and each of the other treatments (table 2). There were no significant differences in species richness among the other treatments or controls. Since the four-burn treatment burned more intensely than the other stands during each burn, greater species richness can likely be attributed more to fire intensity than number of burns. Shannon-Weiner diversity indices did not differ among treatments and controls (table 2). The low abundance of many species found in the four-burn treatment may offer an explanation for the lack of significance in the diversity index even though the species richness is higher.

Importance values (IV(200))for *Andropogon* spp., low panic grass (*Dichanthelium* spp.), and sweet fern (*Comptonia peregrina*) were higher in the four-burn treatment than in the other burns and control. Species found exclusively in the four-burn treatment included Indian grass (*Sorghastrum nutans*), fireweed (*Erictites hieracifolia*), and sweet fern (*Comptonia peregrina*). Species reduced in importance by burning included *Smilax* spp., which were reduced in each burn, and *Galax urceolata* which decreased in the two- and four-burn treatments (table 3).

Stand Structure—Understory tree density was significantly reduced in the two, three, and four-burn treatments compared to control areas (figure 1). Understory density in the four-burn treatment was also lower than that of the one-burn treatment. This pattern suggests that multiple burns are more effective in reducing understory density than single burns, although a single, high-intensity fire could theoretically fires.

Midstory and overstory densities were also significantly reduced in the four-burn treatment compared to other treatments and controls. However, the fire at this site actually crowned in some overstory trees due to the unusually high intensity during all four burns. There was little overstory mortality in any of the other burned areas because fire intensities were lower. Total basal area was reduced in the four-burn treatment compared to other treatments. Basal area in the two-burn treatment was lower than that in the control and one-burn area. Basal area reductions could be a result of the single replication of the two- and four-burn treatments as well as fire intensity in the four-burn treatment.

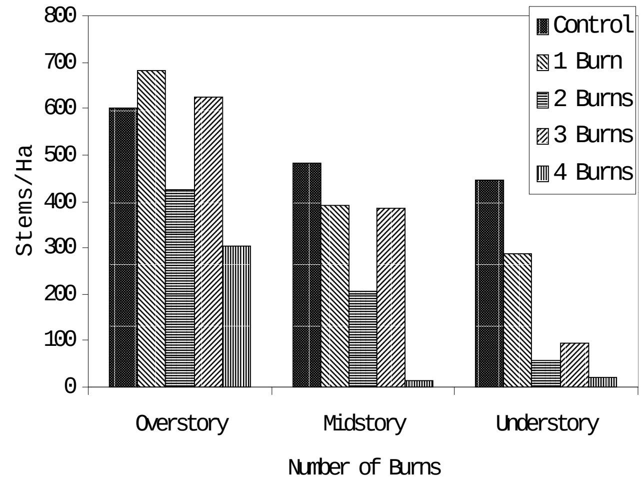


Figure 1—Canopy strata density (stems/ha) for burn treatments and control.

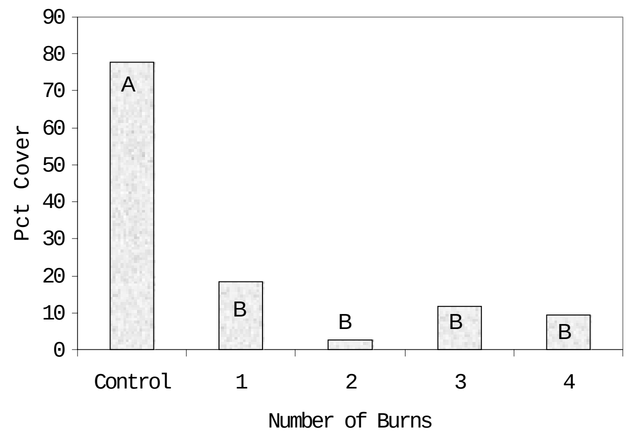


Figure 2—Shrub cover (predominantly mountain laurel) in treatments and control.

Table 3—Importance values (IV200) by species for each treatment

	Number of Burns				
Species	0	1	2	3	4
Andropogon spp.	0.38	0.08	0.31	0.68	11.28
Chimaphila maculata	2.70	0.43	0.54	0.05	0.05
Comptonia peregrina	0.00	0.00	0.00	0.00	10.40
Coreopsis major	0.16	0.08	0.20	0.06	1.25
Dichanthelium spp.	0.24	0.46	0.40	0.58	9.67
Epigaea repens	0.21	0.36	0.31	0.36	0.28
Erichtites hieracifolia	0.00	0.00	0.00	0.00	0.56
Galax urceolata	29.34	29.56	0.85	40.25	6.77
Vaccinium spp.	40.35	63.78	91.58	53.27	39.51
Polygonium convolvulus	0.17	0.61	0.00	0.15	0.00
Pteridium aquilinum	2.36	0.23	5.59	1.40	13.73
Smilax glauca	15.05	2.37	0.21	1.87	4.29
Smilax rotundifolia	8.34	1.78	0.00	1.06	0.11
Sorghastrum nutans	0.00	0.00	0.00	0.00	0.98
Other	0.53	0.32	0.00	0.29	3.28

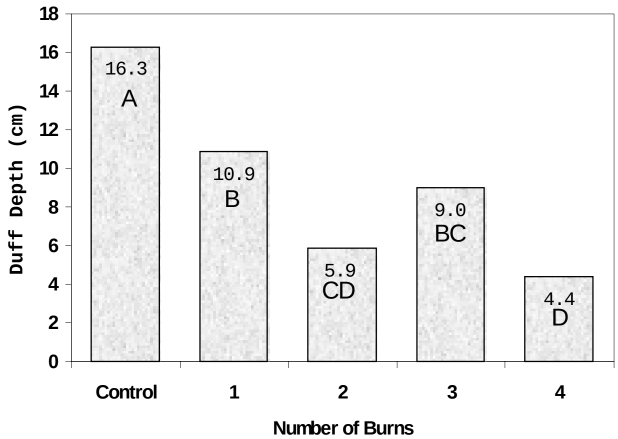


Figure 3—Duff reduction with burningc.

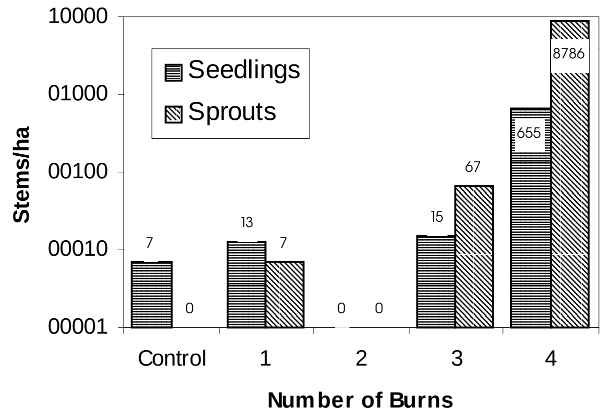


Figure 4—Log-scale of number of pine stems/ha for seedling and sprout regeneration.

Shrub Composition and Structure—Mountain laurel cover was reduced by 59 to 75 percent in the burned treatments but did not significantly differ among burn treatments (figure 2). Repeated winter burns at intervals of several years apparently do not further reduce percent cover of shrubs; rather, the first burn greatly reduces shrub cover and subsequent periodic burns simply maintain this state. Growing season burns might further reduce or even eliminate shrub cover because sprouting vigor is less at this time of year due to lower root reserves.

The height of shrub cover in each burn was significantly lower than that of the controls by 66–91 percent but did not vary from one burn treatment to the next. Mountain laurel was the only shrub found consistently within each area. Other shrubs noted were *Vaccinium* spp., flame azalea (*Rhododendron calendulaceum*), and rosebay rhododendron (*Rhododendron maximum*); however, these shrubs were scattered individuals with little effect on overall cover.

Fuel Loading—Down woody fuel loadings were essentially the same in each of the treatments suggesting frequent burning did not create, or reduce fuel loading. With the exception of the four-burn treatment, burns were generally not of sufficient intensity to kill trees, or if killed, they had not fallen and become surface fuels at the time of sampling. Coarse woody debris on the ground was apparently not consumed by the fires.

Duff depth in each treatment was lower than in the controls, and in most cases, each burn reduced the duff further (figure 3). The exception is the three-burn treatment, which had a mean duff depth slightly, but not significantly, greater than the two burn site. Lack of replication in the two-burn treatment may account for the lower duff depth. Vertical fuel height did not vary in relation to number of burns.

Pine Regeneration—Pine regeneration (seedlings and sprouts) was significantly higher in the four-burn treatment (9440 stems/hectare) than the control (7 stems/hectare) and other burn treatments (avg. 34 stems/hectare) (figure 4). Pine sprouts outnumbered seedlings by a margin of about 13:1 on the four-burn treatment. This pattern suggests that regeneration in this case is not due to the number of fires but rather to intensity of the fires. Had pine regeneration density been due to the number of times the site was burned, a progression in the number of seedlings would likely have been more evident.

Lack of regeneration in the other burn treatments could be caused by the amount of duff remaining on each of the sites after the burns (figure 3), as well as the degree of shading on the one- to three-burn treatments. Waldrop and Brose (1999) suggest that duff depths less than 7.5 centimeters provide a higher probability of germination and seedling survival if a seed source exists. Duff in the three-burn treatment averaged 9.0 centimeters which is still higher than the recommended depth. Results of the two-burn treatment are a bit surprising in that the mean depth was 5.9 centimeters and yet there was no regeneration on sample plots. This depth is not significantly different from the three-burn treatment which is higher than the suggested limit. Growing season burns would likely reduce duff depths more than winter burns and may be more productive in preparing seedbeds. Further study is needed to test this hypothesis. Unfortunately no measure of seed rain or seed viability was conducted so it is unsure how much seed was produced and whether that seed was viable.

Pines are shade-intolerant species and the amount of light reaching the forest floor influences seedling survival. The four-burn treatment had significantly more light reaching the forest floor than the control or any of the other treatments. Reduced shading reflected the intensity with which this stand had been burned on multiple occasions. The type and amount of litter present at seed fall also affects regeneration of Table Mountain pine (Williams, 1990). Most of the litter in these stands was hardwood litter, which reduces the establishment and survival of pine seedlings.

CONCLUSIONS

Multiple understory burns in Table Mountain/pitch pine stands create a more open forest with less cover of shrubs and saplings than unburned forests. Low intensity, dormant-season fires such as those in the one-, two-, and three-burn treatments, however, have little effect on fuel loading and had no quantifiable benefit to the regeneration of Table Mountain and pitch pines. Higher intensity fires such as those in the four-burn treatment created conditions (such as reduced shading and duff depth) that greatly enhanced pine regeneration.

The use of fire to regenerate Table Mountain-pitch pine stands needs further study. Various techniques should be investigated including combinations of thinning and burning, as well as different burning regimes, to develop effective regeneration methods.

ACKNOWLEDGMENTS

We would like to thank the NCWRC for their funding of this study. We would also like to thank Peter Kapeluck, Wayne Carroll, and Helen Mohr for their contributions of time and advice to the study. A special thanks goes out to Dr. Richard Harlow for his consultation on the project.

REFERENCES

Brown, J.K. 1971. A planar intersect method for sampling fuel volume and surface area. Forest Science. 17: 96-102.

Brown, J.K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.

Cain, Michael D.; Wigley, T. Bently; Reed, Derik J. 1998. Prescribed fire effects on structure in uneven-aged stands of loblolly and shortleaf pines. Wildlife Society Bulletin. 26: 209-218.

Delcourt, Paul A.; Delcourt, Hazel R.; Ison, Cecil R.; Sharp, William E.; Gremillion, Kristen J. 1998. Prehistoric use of fire, the Eastern agricultural complex, and Appalachian oak-chestnut forests: Paleoecology of Cliff Palace Pond, Kentucky. American Antiquity. 63: 263-279.

Della-Bianca, Lino. 1990. Silvics of North America, vol. 1: Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 425-432.

Elliot, Katherine J.; Hendrick, Ronald L.; Major, Amy E.; Vose, James M.; Swank, Wayne T. 1999. Vegetation dynamics after a prescribed fire in the southern Appalachians. Forest Ecology Management. 114: 199-213.

Harlow, R.F.; Hooper, R.G. 1971. Forages eaten by deer in the Southeast. Proceedings of the Annual Conference of the Souteastern Association of Game and Fish Committee. 25: 18-46.

Harlow, Richard F. 1977. A technique for surveying deer forage in the southeast. The Wildlife Society Bulletin. 5: 185-191.

Kuehl, Robert O. 2000. Design of Experiments: Statistical Principles of Research Design and Analysis. 2d Ed. Brooks/Cole. 133 p.

Little, Silas; Garrett, Peter W. 1990. Silvics of North America, vol 1: Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 456-462.

Pyne, Stephen J.; Andrews, Patricia L.; Laven, Richard D. 1996. Introduction to Wildland Fire. John Wiley and Sons, Inc., New York. 279-282.

Turrill, N.L., Buckner, E.R.; Waldrop, T.A. 1997. *Pinus Pungens* Lamb. (Table Mountain Pine): A threatened species without fire? In: Greenlee, J., ed., Proceedings of Effects of Fire on Threatened and Endangered Species and Habitats. International Association of Wildland Fire: 301-306.

Waldrop, Thomas A.; Brose, Patrick H. 1998. A comparison of fire intensity levels for stand replacement of table mountain pine (*Pinus pungens* Lamb.) Forest Ecology and Management. 113: 155-166.

Williams, Charles E.; Johnson, W. Carter. 1990. Age structure and maintenance of *Pinus Pungens* in pine-oak forests of Southwestern Virginia. American Midland Naturalist 124: 130-142.

Williams, Charles E.; Lipscomb, Mary V.; Johnson, W.Carter; Nilsen, Erik T. 1990. Influence of leaf litter and soil moisture regime on early establishment of Pinus pungens (Table mountain pine). American Midland Naturalist. 124: 142-153.

IMPACTS OF LONG-TERM PRESCRIBED FIRE ON DECOMPOSITION AND LITTER QUALITY IN UNEVEN-AGED LOBLOLLY PINE STANDS

Michele L. Renschin, Hal O. Liechty, and Michael G. Shelton[1]

Abstract—Although fire has long been an important forest management tool in the southern United States, little is known concerning the effects of long-term fire use on nutrient cycling and decomposition. To better understand the effects of fire on these processes, decomposition rates, and foliage litter quality were quantified in a study investigating uneven-aged loblolly pine (*Pinus taeda* L.) management and prescribed fire in the Upper Coastal Plain of southern Arkansas. A portion of the study area had been burned on a 2 to 3-year cycle since 1981 while another portion of the study area had not been burned. Decomposition rates were determined by placing litterfall from each area into litterbags, installing these bags in the field within each area, and monitoring the litterfall weight loss over a 10-month period. Decomposition potential was determined using a cotton strip assay method. Foliar litter quality was evaluated by determining C, N, P, K, Mg, and Ca concentrations for samples collected from both treatments. Decomposition rate and potential were not significantly different in the burned and unburned areas. However, burning significantly affected foliar litter quality by increasing K, Ca, and Mg concentrations, but decreasing C. Decomposition rates and/or mass loss were significantly higher for foliar litterfall collected from the burned than unburned areas 0.5 months following placement of litterbags in the field.

INTRODUCTION

In the southern pine belt of the United States, the dependence of the pine forest upon fire is well documented (Barnes and others 1998, Wade and Lunsford 1989). Although fire has been considered a damaging agent with few benefits in the past, it is now apparent that fire can be important in the maintenance and establishment of forests (Barnes and others 1998). Today, the use of prescribed fire has become a well-accepted silvicultural practice. Prescribed fire is often used to reduce fuels; prepare sites for regeneration; dispose of logging debris; improve wildlife habitat; manage for competing vegetation and disease; improve aesthetics, access, and grazing; perpetuate fire dependent species; and to manage for endangered and other species (Wade and Lunsford 1989). Fuel burned by prescribed fires may include dead trees, logs, slash, needles, leaves, and other litter (McCullough and others 1998).

The effects of fire on forest ecosystems are complex and can be beneficial or detrimental depending on fire intensity, stand structure, and community composition (Barnes and others 1998). Positive benefits of fire can include increased nutrient uptake, accelerated tree growth, enhanced nutrient cycling (Clinton and others 1996), and improved nutrient availability (Shoch and Binkley 1986, Wade and Lunsford 1989). Negative effects of prescribed fire may include damage to the forest floor and organic matter, nutrient loss, soil erosion, decreased soil aeration and penetrability, and vegetation injury or mortality (Wade and Lunsford 1989).

Because prescribed fire is an important part of southern pine management, it is essential to determine how frequent application of fire over long periods of time alters forest ecosystem processes. One such process that could be altered by fire is organic matter decomposition. Decomposition and oxidation of litterfall, as well as the subsequent mineralization of nutrients contained in the litterfall, regulate the accumulation of organic matter and account for a substantial amount of the nutrients that are cycled in forest ecosystems (Fogel and Cromak 1977). With this in mind, we superimposed a litter decomposition study within an ongoing investigation of the silvicultural effects of fire in uneven-aged loblolly pine (*Pinus taeda* L.) stands in southeastern Arkansas. The objectives of our study were to determine: (1) if pine foliar litterfall on burned areas decomposes at a different rate than litterfall on unburned areas, (2) if pine foliar litterfall collected from burned areas decomposes at a different rate than litterfall collected from unburned areas, and (3) if decomposition potential is different between burned and unburned areas. These objectives were accomplished by examining pine litterfall decomposition, cotton tensile strength loss, and foliar nutrient contents.

METHODS

Study Area

The study was located in the Crossett Experimental Forest in Ashley County, Arkansas, at 32° 02' N mean latitude and 91° 56' W mean longitude. The study area is 53 m above mean sea level with nearly level topography. Annual precipitation averages 140 cm. Soils are predominantly Bude and Providence silt loams (fine-silty, mixed, thermic, Glossaquic

[1]Graduate Research Assistant, Assistant Professor, School of Forest Resources, University of Arkansas-Monticello, Monticello, AR 71656-3468, Research Forester, Southern Research Station, Monticello, AR 71656-3516, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

and Typic Fragiudalfs, respectively) that have an impervious layer at a depth of 50-100 cm, which impedes internal drainage and root growth (Gill and others 1979). Soil reactivity varies from medium acid to very strongly acid. Site index for loblolly pine is 27 m at age 50 (Cain 1993).

Treatments

Starting in the late 1930's, the study sites were managed using uneven-aged silviculture with single-tree selection and the complete exclusion of fire (Cain 1993). After the late 1960's, no harvesting, burning or vegetative control was performed until 1980. The following treatments were initiated in January of 1981 and consisted of: 1) an unburned control, 2) an irregular winter burn [every 2-3 years], 3) a winter burn every 5 years, and 4) a winter burn every 10 years (Cain and others 1998). The treatments were installed in each of the three 16-ha compartments. Four contiguous 1-ha plots comprised a 4-ha burn treatment in each compartment. Each 1-ha plot had an interior measurement plot of 0.65 ha that was surrounded by a 10-m wide isolation strip. For the purposes of this study, only the unburned control and irregular burn treatments were used. In 1992, the unburned control plots were treated with a broadcast application of Arsenal AC™ herbicide (1.7 kg a.i.) in 113 liters of water/ha using skidders. The most recent burn on the irregular burned treatment was conducted in October 1998.

All measurements occurred in the interior 0.65-ha plot located within a selected 1-ha plot in a treatment. Each of the selected 1-ha plots has been maintained at a residual pine basal area of 14 m^2/ha using single-tree selection on a six year harvesting schedule since 1980. Thus a total of six plots were used in the study, one unburned control and one irregularly burned plot in each of the three compartments. Within each of the measurement plots, three 4 x 4 m subplots were located. Vegetation within each of the 4 x 4 m subplots was trimmed to ground level in three strips (approximately 40 cm wide) for litterbag installation.

Litterbags

The litterbag method (Melillo and others 1982, Lockaby and others 1995) was utilized to measure decomposition rates on both treatments. Each nylon litterbag was 30 cm x 30 cm with a mesh size of 5 mm on the top and 2 mm on the bottom. In the fall of 1999, pine foliar litterfall was collected from all plots within the two treatments. The litter was air dried, mixed by treatment, and stored for later use in litterbags.

One set of litterbags was filled with 20 g of air-dried pine foliar litter collected from the burned treatments and a second set of litterbags was filled with 20 g of air-dried pine foliar litter collected from the unburned control treatment. Litterbags from both sets were placed on the forest floor surface in each of the trimmed strips located in each subplot on February 28, 2000. One litterbag from each set (foliage collected from the unburned and irregular burned treatments) was collected from each subplot after 0.5, 1, 2, 5, 7, and 10 months. Litterbags were transported in plastic bags to the laboratory, where all foreign material was removed. Litter was dried at 70° C for 48 hours and weighed. Loss on ignition from each sample was determined by heating the litter to 375° C for 16 hours. These values were then used to give a corrected (ash free) mass. The corrected mass, which is free from contamination by mineral soil, was used for statistical analysis. In addition, a correction factor was applied to adjust the initial air-dried weight of the litter to an oven-dried basis.

Cotton Strip Assay

A cotton strip assay (Latter and Howson 1977, Latter and Walton 1988, Butterfield 1999) was used to evaluate decomposition potential in the burned and unburned treatments. This technique is useful in assessing decomposition potential because the cloth is a uniform substrate and allows for examination of decomposition potential at different depths. In both April and July of 2000, sets of five 12 x 30 cm sheets of burial cloth manufactured by Shirley Dyeing and Finish Ltd. (Sagar 1988) were buried on each subplot to a depth of 25 cm using methods described by Latter and Howson (1977). After 30 days of incubation, the sheets were removed for analysis. In the laboratory, strips were cut and frayed to a width of 1 cm at each of four depths (3-5, 7-10, 12-15, and 21-24 cm). Tensile string was determined for each strip using a Scanpro Alwetron TH-1 tensile strength tester. Strips were equilibrated in a climate-controlled room at 50 percent relative humidity and 20° C for 2 weeks prior to strength testing. The tensile strengths of strips from incubated sheets were subtracted from the tensile strengths of strips cut from control sheets that had been installed in the soil and immediately removed at the start of each incubation period. The use of the control sheets adjusted for the loss of tensile strength during installation and removal. The difference of these two values divided by the control strip tensile strength gave percent tensile strength loss for the incubated strips. Reduction of tensile strength calculated in this way reflects oxidation of carbon through decomposition.

Litter Quality

Several studies have used litter quality as a variable to assess decomposition rates (Fogel and Cromak 1977, Taylor and others 1989). Initial quality of loblolly pine litterfall was assessed for each treatment. Seven subsamples of the litter collected from each treatment were dried, ground, and analyzed for macronutrient concentrations. Concentrations of P, K, Ca, Mg, and S in the litterfall were determined using inductance coupled plasma (University of Arkansas, Soil Test Laboratory, 1990) after a perchloric acid digestion (Alder and Wilcox 1985). N and C concentrations were determined by combustion using a LECO CN2000 analyzer.

Statistical Design

Corrected mass loss from the litterbags was analyzed using ANOVA with a split-plot through space and time design with compartment as the blocking factor. The cotton strip data were analyzed using ANOVA with a split-split plot design. The litter quality data was analyzed using a paired t-test. All tests were done with a significance level at a = 0.05.

RESULTS AND DISCUSSION

After 10 months, there was no statistical evidence that 20 years of prescribed fires had significantly altered decomposition rates at these sites (figure 1). The corrected mass loss of the pine litterfall did not significantly differ between the

Table 1—Initial nutrient concentration of foliar litter collected from irregular burned and unburned treatments in three uneven-aged loblolly pine stands in Crossett, AR

Nutrient	Source	Mean Concentration (pct)	Standard Error
C	Burned	47.8 a[a]	0.083
	Unburned	48.2 b	0.104
N	Burned	0.43 a	0.006
	Unburned	0.43 a	0.012
P	Burned	0.26 a	0.001
	Unburned	0.27 a	0.002
K	Burned	0.13 a	0.004
	Unburned	0.11 b	0.007
Ca	Burned	0.36 a	0.006
	Unburned	0.33 b	0.011
Mg	Burned	0.09 a	0.002
	Unburned	0.08 b	0.003
S	Burned	0.04 a	0.001
	Unburned	0.04 a	0.001

[a] Concentrations for a given nutrient followed by the same letter are not significantly different at a = 0.05.

burned and unburned treatments for any of the collection dates. However, corrected mass of the litterfall was consistently lower on average in bags collected from the unburned than the burned treatment. Differences in corrected mass between the treatments were less than 2.2 percent for all collection periods.

Similar to the corrected mass loss of litter in the bags, cotton tensile strength loss (decomposition potential), did not significantly differ between the burned and unburned treatments for a given incubation period or depth (figure 2). Cotton tensile strength loss varied among incubation periods and depths but showed no consistent trends between treatments. Variation due to depth and incubation period (April or July) was generally much greater than variation between treatments (figure 2).

In contrast, corrected mass from litterbags containing pine litterfall from the irregular burned treatment was significantly lower than litterbags containing pine litterfall collected from the unburned treatment (figure 3). At the 0.5-month collection period, litterfall collected from the irregular burned treatment had lost 56 percent more mass than litterfall collected from unburned areas. After this time, mass of the two litterfall sources remained significantly different throughout the 10 months. The difference in mass between the two sources remained at approximately the same levels detected after ½ months. These results suggest that long-term prescribed fire can indirectly affect mass loss, and perhaps decomposition. The litterfall collected from the burned areas either decomposed faster or experienced rapid leaching after only 2 weeks. This suggests that there is an inherent difference in nutrient concentration, chemical composition, or possibly physical characteristics between the litterfall sources and that these differences need to be quantified.

Nutrient analysis of the collected litter showed no significant differences for N, P, S, or C/N ratios (table 1). However, litterfall collected from the burned treatment contained significantly higher concentrations of K, Ca, and Mg but lower concentrations of C than in litterfall from the unburned treatments. These differences, although small, may explain a portion of the initial differences in corrected mass loss in litterfall from the two treatment areas. It is also possible that differences in physical characteristics or soluble sugar contents of the litterfall contributed to the initial difference in weight loss. Examining nutrient contents in combination

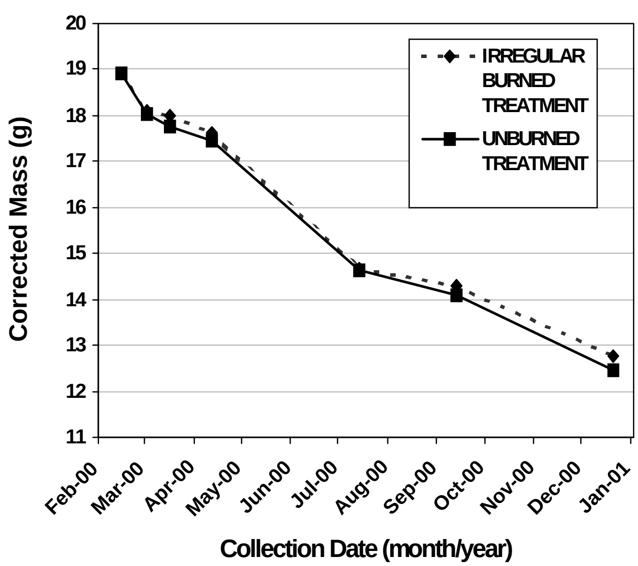


Figure 1—Corrected mass loss of decomposing foliar litter placed in irregular burned and unburned treatments in three uneven-aged loblolly pine stands in southeastern Arkansas.

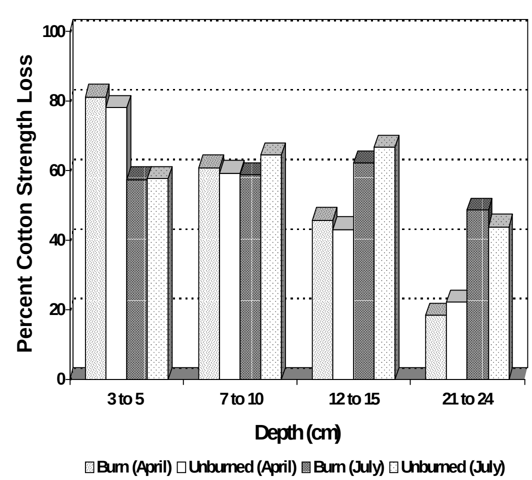


Figure 2—Percent cotton tensile strength loss over 30-day periods in April and July 2000 in irregular burned and unburned treatments in three uneven-aged loblolly pine stands in southeastern Arkansas.

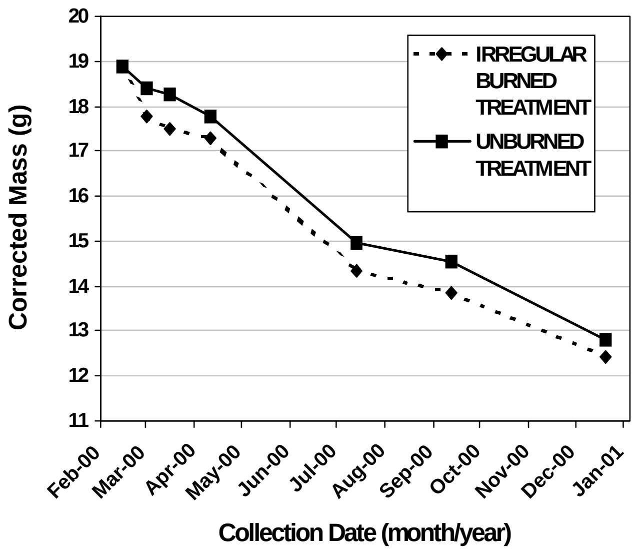


Figure 3—Corrected mass loss of decomposing foliar litter collected from irregular burned and unburned treatments in three uneven-aged loblolly pine stands in southeastern Arkansas.

with cellulose, lignin, or soluble sugar concentrations could have provided a better explanation of the corrected mass loss, but, we did not perform those analyses.

ACKNOWLEDGMENTS

This work was jointly supported by the Arkansas Forest Resources Center and the Southern Research Station. We thank Drs. Lynne Thompson and Paul Doruska for their technical assistance. In addition, the authors thank Kenny Davis, Steve Tackett, Adrian Grell, Jim Schmierer, Rhona Jitta, and Sam Clark for help with work in the field and laboratory.

REFERENCES

Adler, P.R. and Wilcox, G.W. 1985. Rapid perchloric acid digest methods for analysis of major elements in plant tissue. Communication in Soil Science and Plant Analysis. 16: 1153-1163.

Barnes, B.V.; Zak, D.R.; Denton, S.R.; Spurr, S.H. 1998. Forest ecology. New York, NY: John Wiley and Sons, Inc. 774 p.

Butterfield, J. 1999. Changes in decomposition rates and Collembola densities during the forestry cycle in conifer plantations. Journal of Applied Ecology. 36: 92-100.

Cain, M.D. 1993. A 10 year evaluation of prescribed winter burns in uneven-aged stands of Pinus taeda L. and P. echinata Mill.: woody understory vegetation response. International Journal of Wildland Fire. 3: 13-20.

Cain, M.D.; Wigley, T.B.; Reed, D.J. 1998. Prescribed fire effects on structure in uneven-aged stands of loblolly and shortleaf pines. Wildlife Society Bulletin. 26: 209-218.

Clinton, B.D.; Vose, J.M.; Swank, W.T. 1996. Shifts in above-ground and forest floor carbon and nitrogen pools after felling and burning in the southern Appalachians. Forest Science. 42: 431-440.

Fogel, R.; Cromak, K. 1977. Effect of habitat and substrate quality on Douglas-fir litter decomposition in western Oregon. Canadian Journal of Botany. 55: 1632-1640.

Gill, H.V.; Avery, D.C.; Larance, F.C.; Fultz, C.L. 1979. Soil survey of Ashley County, Arkansas. Washington, DC: U.S. Department of Agriculture Soil Conservation Service and Forest Service. Fayetteville, AR: Arkansas Agricultural Experiment Station. 174 p.

Latter, P.M.; Howson, G. 1977. The use of cotton strips to indicate cellulose decomposition in the field. Pedobiologia. 17: 145-155

Latter, P.M.; Walton, D. 1988. The cotton strip assay for cellulose decomposition studies in soil: History of the assay and development. In: Harrison, A.F., and others, eds. Cotton strip assay: An index of decomposition in soils. Grange-Over-Sands, England: Institute of Terrestrial Ecology: 7-9.

Lockaby, B.G.; Miller, J.H.; Clawson, R.G. 1995. Influences of community composition on biogeochemistry of loblolly pine (*Pinus taeda*) systems. American Midland Naturalist. 134: 176-184.

McCullough, D.G.; Werner, R.A.; Neumann, D. 1998. Fire and insects in northern and boreal forest ecosystems of North America. Annual Review of Entomology. 43: 107-127.

Melillo, J.M.; Aber, J.D.; Muratory, J.F. 1982. Nitrogen and lignin control of hardwood leaf litter dynamics. Ecology. 63: 624-626.

Sagar, B.F. 1988. The Shirley soil burial test fabric and tensile strength testing as a measure of biological breakdown of textiles. In: Harrison, A.F. and others (eds.). Cotton strip assay: An index of decomposition in soils. Grange-Over-Sands, England: Institute of Terrestrial Ecology: 11-16.

Shoch, P.; Binkley D. 1986. Prescribed burning increased nitrogen availability in a mature loblolly pine stand. Forest Ecology and Management. 14: 13-22.

Taylor, B.R.; Parkinson, D.; Parsons W.F.J. 1989. Nitrogen and lignin contents as predictors of litter decay rates: a microcosm test. Ecology. 70: 97-104.

EFFECTS OF PRESCRIBED FIRE ON HERPETOFAUNA WITHIN HARDWOOD FORESTS OF THE UPPER PIEDMONT OF SOUTH CAROLINA: A PRELIMINARY ANALYSIS

Thomas M. Floyd, Kevin R. Russell, Christopher E. Moorman, David H. Van Lear, David C. Guynn, Jr., and J. Drew Lanham[1]

Abstract—Despite a large body of knowledge concerning the use of prescribed burning for wildlife management, amphibians and reptiles (collectively, herpetofauna) have received relatively little attention regarding their responses to fire. With few exceptions, previous studies of herpetofauna and prescribed burning have been confined to fire-maintained, pine-dominated ecosystems in the Coastal Plain of the southeastern United States. We initiated a study to examine effects of prescribed burning on herpetofauna in Piedmont upland hardwood stands. Linear drift fence arrays with pitfall traps were installed within control and treatment plots to assess effects of burn treatments through analysis of species captures. Treatment plots were subjected to low intensity winter and growing season fire. The initial prescribed burn treatments were implemented in February and March (1999) while the second prescribed burn treatments were implemented in April (2000). All treatment plots were burned with strip head fires set 10-20 feet apart resulting in flame lengths averaging less than 1 foot. Direct searching and drift fence sampling immediately after each prescribed burn revealed 1) no evidence of direct herpetofaunal mortality, and 2) no evidence of emigration from burn plots. Statistical analysis of data through the installation of the second burn (May 1999 through April 2000) revealed no significant difference between burned and unburned treatments for abundance, richness (S), diversity (H'), or evenness (J')($P > 0.1$) of the herpetofaunal community.

INTRODUCTION

Prescribed burning is used to achieve a variety of silvicultural objectives including controlling heavy fuel accumulation, exposing mineral soil, releasing available nutrients for seedbed preparation, and controlling certain diseases, insects, and competing vegetation (Hunter 1990, Pyne and others 1996). Prescribed burning is also an important tool for wildlife management because it influences the amount and type of food and cover by modifying habitat structure. Despite a large body of knowledge concerning the use of prescribed burning for wildlife management, amphibians and reptiles (collectively, herpetofauna) have received relatively little attention regarding their responses to fire (deMaynadier and Hunter 1995, Harlow and Van Lear 1981, 1987, NCASI 1999, NCASI 1993, Russell and others 1999, Smith 2000). With few exceptions (i.e., Ford and others 1999, Kirkland and others 1996), previous studies of herpetofauna and prescribed burning have been confined to fire-maintained, pine-dominated ecosystems in the southeastern Coastal Plain (e.g., Lyon and others 1978, Means 1978, Means and Campbell 1981, McLeod and Gates 1998). Because little data are available concerning responses of herpetofauna to fire in other regions and forest types, we initiated a study to examine the effects of prescribed burning on herpetofauna in Piedmont upland hardwood stands.

Increased demands on southeastern forests, both public and private, are expected to continue (Sharitz and others 1992, USDA Forest Service 1988). As demands on timber resources increase, the use of prescribed fire as a forest management tool will continue to expand. If herpetofauna are to be considered in future forest management decisions, the effects of forestry practices such as prescribed burning on herpetofauna must be better understood. Objectives of this research effort included the determination of both the direct and indirect effects of prescribed fire on the diversity and abundance of herpetofaunal species within pine-hardwood forests in the Piedmont of the Southeast. Questions addressed within this research are of particular relevance in light of the utilization of prescribed fire in hardwood-dominated forest habitats within recent research to regenerate oak species (e.g., Barnes and Van Lear 1998, Brose and others 1999a, Brose and others 1999b, Van Lear 1991).

[1]Graduate Research Assistant, Professor, Assistant Professor, School of Natural Resources, Department of Forest Resources, 261 Lehotsky Hall, Clemson University, Clemson, South Carolina 29634-0331; Wildlife Research Biologist, Willamette Industries, Inc., Coast Operations, P.O. Box 488, Dallas, Oregon 97338-0488; Assistant Professor, Department of Forestry, North Carolina State University, Box 8003, Raleigh, North Carolina 27695-8003, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

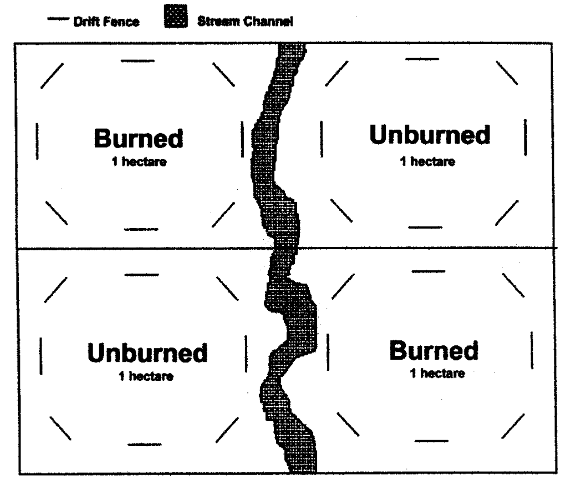


Figure 1—Experimental design of treatment and control plots of each of the three research sites, Clemson University Experimental Forest, Clemson, South Carolina, May 1999-April 2000.

METHODS AND STUDY AREA

Study Design and Site Selection

Study sites were located within the northern portion of the 17,356 acre Clemson University Experimental Forest (CUEF) in Pickens County in the Upper Piedmont of northwestern South Carolina. The CUEF is characterized by slightly to moderately rolling hills with elevations to 1,000 feet above sea level. Soil associations are Pacolet-Madison-Wilkes and Cecil-Hiawassee-Catuala (Typic Kanhapludults and Typic Hapludalfs). Soils are strongly acidic, firm and clayey being derived from gneiss, mica schist, hornblende schist and schist (Smith and Hallbeck 1979).

We evaluated the effects of prescribed burning on herpetofauna species found within three sites located along separate stream drainages within hardwood forest stands. These sites were selected based on similarity of species composition (dominant vegetation), vegetative structure, and aspect. The upland hardwood stands adjacent to each stream were divided into approximately 2.5 acre (1 hectare) control (unburned) and burn treatments (figure 1), for a total of six burn and control plots, respectively.

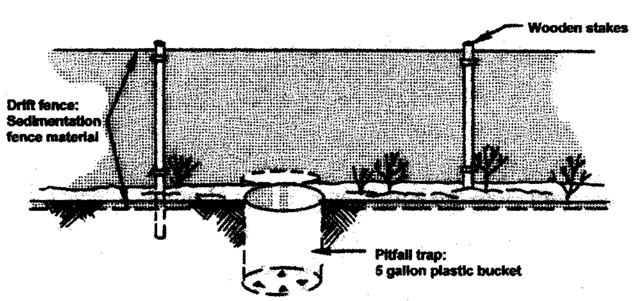


Figure 2—Schematic of pitfall-drift fence array construction, Clemson University Experimental Forest, Clemson, South Carolina, May 1999-April 2000 (diagram adapted from: Gibbons and Semlitsch 1982).

Herpetofaunal Sampling

Herpetofaunal species composition of the study sites were determined through the capture of individuals within pitfall-drift fence arrays. Linear drift fence arrays with pitfall traps (Gibbons and Semlitsch 1982) were installed along the perimeter of each plot to sample small terrestrial herpetofauna. Each drift fence array consisted of a 30 foot section of silt cloth with 2 pitfall traps (each a 5 gallon bucket, buried flush with the soil surface) at each end of the fence for a total of 4 pitfalls/fence (figure 2). Each plot had eight drift fences for a total of 96 drift fences and 384 pitfall traps among the three sites. All herpetofauna captured were identified to species, sex (when possible), age class, measured to the nearest mm in snout-vent length (SVL) and total length (TL), and marked. After all information was recorded and a mark assigned, herpetofauna were released on the opposite side of the fence from which they were captured.

Prescribed Fire Treatments

The initial prescribed burn treatments were implemented in February 1999 (sites 1, 2) and March 1999 (site 3) with strip head fires set 15-30 feet apart resulting in flame lengths averaging slightly over 1 foot. The second prescribed burn treatments (intended to be “growing season” burns) were implemented in April 2000 for all three sites with strip head fires set 10-20 feet apart. Flame lengths averaged less than 1 foot because of light fuel loading.

Statistical Analysis

We calculated species richness (S; Margalef 1958), evenness (J’; Pielou 1969), and diversity (H’; Shannon 1948) for amphibian and reptile communities at each site. Student’s t-tests (Brower and others 1990) were calculated to compare mean values of abundance, richness, evenness, and diversity between burned and unburned (control) treatments. We also determined abundance for each order or suborder (or family), (i.e., frogs, toads, salamanders, newts, turtles, lizards, and snakes). We then compared the mean values of abundance, richness, evenness, and diversity for each of these taxonomic groups between burned and unburned site treatments using t-tests.

RESULTS

Direct searching and drift fence sampling immediately after prescribed burns revealed 1) no evidence of direct herpetofaunal mortality, and 2) no evidence of emigration from burn plots. Within the data analyzed (May 1999 through April 2000), 29 species of amphibians and reptiles were captured from the three drainages combined. Four species of the 29 were captured only in burned plots, while 5 species were captured only in unburned plots (table 1). Preliminary analysis of data following the first prescribed fire treatment using indices of species overlap (i.e., a measure of the number of shared species) indicated greater differences between sites (e.g., site 1 vs. site 2: 0.615) than between burn and control treatments (0.800). Statistical analysis of data through the installation of the second burn (May 1999 through April 2000) revealed no significant difference between burned and unburned

Table 1–Herpetofaunal taxa captured from burned and control plots in the Clemson University Experimental Forest, South Carolina, May 1999-April 2000

Taxonomic group	Common name	Treatment Burn	Treatment Control
AMPHIBIA (amphibians)			
Caudata (salamanders)			
Desmognathus fuscus	(northern dusky salamander)	*	*
Desmognathus monticola	(seal salamander)		*
Desmognathus ocoee	(Ocoee salamander)	*	*
Desmognathus quadramaculatus	(black-bellied salamander)		*
Eurycea cirrigera	(southern two-lined salamander)	*	*
Eurycea guttolineata	(three-lined salamander)		*
Gyrinophilus porphyriticus dunni	(Carolina spring salamander)	*	*
Notophthalmus v. viridescens	(red-spotted newt)	*	*
Plethodon chlorobryonis	(Atlantic Coast slimy salamander)	*	*
Pseudotriton ruber schencki	(black-chinned red salamander)	*	*
Total salamanders		**51**	**77**
Anura (frogs and toads)			
Acris c. crepitans	(eastern cricket frog)	*	*
Bufo a. americanus	(eastern American toad)	*	*
Bufo terrestris	(southern toad)	*	
Bufo fowleri	(Fowler's toad)	*	*
Hyla chrysoscelis/versicolor	(gray treefrog)		*
Rana clamitans melanota	(northern green frog)	*	
Total anurans		**57**	**48**
Total amphibians		**108**	**125**
REPTILIA (reptiles)			
Serpentes (snakes)			
Carphophis a. amoenus	(eastern worm snake)	*	*
Diadophis punctatus edwardsii	(northern ring-necked snake)	*	*
Elaphe o. obsoleta	(black ratsnake)	*	*
Heterodon platirhinos	(eastern hog-nosed snake)		
*			
Nerodia s. sipedon	(common watersnake)	*	
Storeria o. occipitomaculata	(northern red-bellied snake)		*
Tantilla coronata	(southeastern crowned snake)	*	
Total snakes		**16**	**20**
Lacertilia (lizards)			
Anolis c. carolinesis	(northern green anole)	*	*
Eumeces fasciatus	(common five-lined skink)	*	*
Eumeces inexpectatus	(southeastern five-lined skink)	*	*
Sceloporus undulatus hyacinthinus	(northern fence lizard)	*	*
Scincella laterallis	(little brown skink)		*
*			
Total lizards		**69**	**54**
Testudines (turtles)			
Terrapene c. carolina	(eastern box turtle)	*	*
Total turtles		**2**	**3**
Total reptiles		**87**	**77**
Total captures		**195**	**203**

treatments for abundance, richness (S), diversity (H'), or evenness (J')(P > 0.1). Analysis of abundance, richness, diversity, and evenness for taxonomic groups (frogs, toads, salamanders, newts, turtles, lizards, and snakes) revealed no significant difference with respect to treatment (P > 0.1). However, captures of individuals tended to be greater within unburned (control) plots for salamanders and snake species (figure 3) and may prove significant as more data becomes available with continued sampling.

DISCUSSION

The lack of statistically significant differences in data between treatments may be attributed to the limited subset of project data available for this preliminary data analysis. Significant differences between burned and control treatments may be found in future analyses of data collected over a greater temporal scale. We believe that the differences (although not statistically significant) observed in salamander species capture between burned and unburned plots are an indirect result of the low intensity prescribed fire treatments. Surface fires introduced to the treatment plots substantially reduced or completely eliminated the litter mass, but not the duff mass, on the forest floor until leaf fall the following autumn.

Ash (1995) postulated that reductions in litter mass, depth, and moisture may contribute to the disappearance of terrestrial salamander species as they depend on a moist environment for dermal respiration and on litter as their primary foraging substrate. Furthermore, low intensity surface fire in mature upland mixed hardwood stands may reduce moisture content of the soil surface through the elimination of leaf litter and by increasing the amount of solar radiation reaching the soil surface (Barnes and Van Lear 1998).

Plethodontid salamanders (the lungless family of salamanders with an entirely terrestrial life cycle) spend roughly 70 - 80 percent of their lives in underground burrows, emerging at night to forage within the leaf litter under favorable conditions (Ash 1995, Taub 1961). The combined effect of decreased surface soil moisture and repeated reduction or elimination of leaf litter mass by prescribed fire treatments could result in a decrease in the relative humidity in these burrows, resulting in the gradual decline of salamander populations within burned plots, especially in more xeric sites (e.g., ridge tops).

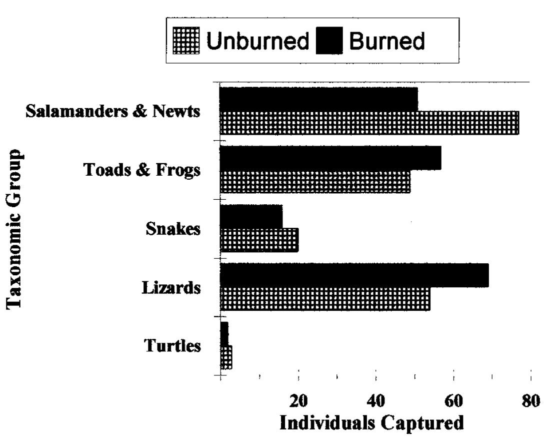


Figure 3—Total number of individuals captured by taxonomic group following burning in the Clemson University Experimental Forest, Clemson, South Carolina, May 1999-April 2000.

SUMMARY AND CONCLUSIONS

Preliminary analysis of a subset of project capture data (May 1999 through April 2000) revealed no significant difference between burned and unburned treatments with respect to abundance, richness (S), diversity (H'), or evenness (J')(P > 0.1). Analysis of abundance, richness, diversity, and evenness for taxonomic groups (frogs, toads, salamanders, newts, turtles, lizards, and snakes) revealed no significant difference with respect to treatment (P > 0.1). Based on these preliminary analyses, the use of prescribed fire in hardwood forests of the Upper Piedmont of South Carolina does not appear to have a measurable negative effect on herpetofaunal communities associated with these upland hardwood habitats. However, we believe that the differences (although not statistically significant) observed in salamander species capture between burned and unburned plots are an indirect result of the low intensity prescribed fire treatments. We therefore suggest continued monitoring of the research sites and analysis of additional data, as data collected over a greater span of time may reveal differences among species such as Plethodontid salamanders. Analysis of additional data will be conducted in the near future.

ACKNOWLEDGMENTS

Funding for this project was provided by the McIntire-Stennis Cooperative Forestry Research Program and the Clemson University Department of Forest Resources. We thank J. Williams for his considerable contribution to the statistical analyses.

REFERENCES

Ash, A.N. 1995. Effects of clear-cutting on litter parameters in the southern Blue Ridge Mountains. Castanea. 60(2): 89-97.

Barnes, T.A.; Van Lear, D.H. 1998. Prescribed fire effects on advanced regeneration in mixed hardwood stands. Southern Journal of Applied Forestry. 22(3): 138-142.

Brose, P.; Van Lear, D.H.; Cooper, R. 1999a. Using shelterwood harvests and prescribed fire to regenerate oaks stands on productive upland sites. Forest Ecology and Management. 113(2-3): 125-141.

Brose, P.; Van Lear, D.H.; Keyser, P.D. 1999b. A shelterwood-burn technique for regenerating productive upland oak sites in the Piedmont region. Southern Journal of Applied Forestry. 23(3): 158-163.

Brower, J.; Zar, J.; von Ende, C. 1990. Field and laboratory methods of general ecology. 3rd ed. Dubuque, Iowa: W.C. Brown Publishers. 237 p.

DeMaynadier, P.G.; Hunter, M.L., Jr. 1995. The relationship between forest management and amphibian ecology: a review of the North American literature. Environmental Reviews. 3: 230-261.

Ford, W.M.; Menzel, M.A.; McGill, D.W.; Laerm, J.; McCay, T.S. 1999. Effects of a community restoration fire on small mammals and herpetofauna in the Southern Appalachians. Forest Ecology and Management. 114(2-3): 233-244.

Gibbons, J.W.; Semlitsch, R.D. 1982. Terrestrial drift fences with pitfall traps: An effective technique for quantitative sampling of animal populations. Brimleyana. 7: 1-16.

Harlow, R.F.; Van Lear, D.H. 1981. Silvicultural effects on wildlife habitat in the South (an annotated bibliography)1953-1979. Department of Forestry Technical Paper Number 14. Clemson University, Clemson, SC.

Harlow, R.F.; Van Lear, D.H. 1987. Silvicultural effects on wildlife habitat in the South (an annotated bibliography)1980-1985. Department of Forestry Technical Paper Number 17. Clemson University, Clemson, SC.

Hunter, M.A., Jr. 1990. Wildlife, forests, and forestry: principles of managing forests for biological diversity. Englewood Cliffs, New Jersey: Prentice Hall. 370 p.

Kirkland, G.L., Jr.; Snoddy, H.W.; Miller, T.L. 1996. Impact of fire on small mammals and amphibians in central Appalachian deciduous forest. American Midland Naturalist. 135(2): 253-260.

Lyon, L.J.; Crwaford, H.S.; Czuhai, E.; Fredriksen, R.L.; Harlow, R.F.; Metz, L.J.; Pearson, H.A. 1978. Effects of fire on fauna: state-of-knowlege review. General Technical Report, WO-6. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 22 p.

Margalef, D.R. 1958. Information theory in ecology. Yearbook of the Society for General Systems Research. 3: 36-71.

McLeod, R.F.; Gates, J.E. 1998. Response of herpetofaunal communities to forest cutting and burning at Chesapeake Farms, Maryland. American Midland Naturalist. 139(1): 164-177.

Means, D.B. 1978. The Pine Barrens treefrog: fire, seepage bogs, and management implications. In: Proceedings of the rare and endangered wildlife symposium. R.R. Odom; Landers, L., eds. Georgia Department of Natural Resources, Game and Fish Division, Technical Bulletin WL -4. Athens, GA.: 77-81.

Means, D.B.; Campbell, H.W. 1981. Effects of prescribed fire on amphibians and reptiles. In: Wood, G.W.,ed. Prescribed fire and wildlife in southern forests: Proceedings of a symposium; 1981 Apr 6-8; Myrtle Beach, SC. Georgetown, SC: The Belle Baruch Forest Science Institute of Clemson University: 89-96.

National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI). 1993. Forestry, wildlife, and habitat in the East: An annotated bibliography, 1986-1990. Technical Bulletin No. 651. New York: National Council of the Paper Industry for Air and Stream Improvement, Inc: 1-317, appendices.

National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI). 1999. Forestry, wildlife, and habitat in the East: An annotated bibliography, 1991-1995. Technical Bulletin No. 781. Research Triangle Park, N.C.: National Council of the Paper Industry for Air and Stream Improvement, Inc: 1-725, appendices.

Pielou, E.C. 1969. An introduction to mathematical ecology. New York: Wiley-Interscience. 286 p.

Pyne, S.J.; P.L. Andrews; R.D. Laven. 1996. Introduction to wildland fire. Second edition. New York: John Wiley and Sons. 769 p.

Russell, K.R.; Van Lear, D.H.; Guynn, D.C., Jr. 1999. Prescribed fire effects on herpetofauna: review and management implications. Wildlife Society Bulletin**.** 27(2): 374-384.

Shannon, C.E. 1948. A mathematical theory of communication. Bell System Technical Journal. 27(1,2): 379-423; 27(3): 623-656.

Sharitz, R.R.; Boring, L.R.; Van Lear, D.H.; Pinder, J.E., III. 1992. Integrating ecological concepts with natural resource management of southern forests. Ecological Applications. 2(3): 226-237.

Smith, B.R.; Hallbeck, D.C. 1979. General soil map, South Carolina. South Carolina Agricultural Experiment Station, Clemson University, Clemson, South Carolina.

Smith, J.K.,ed. 2000. Wildland fire in ecosystems: effects of fire on fauna. General Technical Report, RMRS-42-vol. 1. Ogden, UT: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 p.

Taub, F.B. 1961. The distribution of the red-backed salamander, *Plethodon c. cinereus*, within the soil. Ecology. 42(4): 681-698.

U.S. Department of Agriculture, Forest Service. 1988. The South's fourth forest: alternatives for the future. Forest Resources Report No. 24. Washington, D.C.: U.S. Department of Agriculture, Forest Service.

Van Lear, D.H. 1991. Fire and oak regeneration in the southern Appalachians. In: Proceedings: fire and the environment: ecological and cultural perspectives. General Technical Report SE-69. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 15-21.

ECTOMYCORRHIZAE OF TABLE MOUNTAIN PINE AND THE INFLUENCE OF PRESCRIBED BURNING ON THEIR SURVIVAL

Lisa E. Ellis, Thomas A. Waldrop, and Frank H. Tainter[1]

Abstract—High-intensity prescribed fires have been recommended to regenerate Table Mountain pine (*Pinus pungens)*. However, tests of these burns produced few seedlings, possibly due to soil sterilization. This study examined abundance of mycorrhizal root tips in the field after a high-intensity fire and in the laboratory after exposing rooting media to various temperatures. One- and two-year old seedlings in the field had abundant mycorrhizal root tips formed by symbiotic relationships with at least three fungal species. Laboratory tests showed reduced mycorrhizal root tip formation only after prolonged exposure to very high temperatures. This study suggests that poor regeneration after high-intensity prescribed fires was not caused by a lack of mycorrhizal fungi.

INTRODUCTION

There is increasing evidence that fire is an important component of the Table Mountain pine (*Pinus pungens*) community. Although not currently threatened or endangered, Table Mountain pine is being replaced by more shade-tolerant hardwoods in the Appalachian Mountains because of fire exclusion (Van Lear and Waldrop 1989). Early work suggested that Table Mountain pine requires a very high intensity fire in order to promote adequate regeneration (Zobel 1969). However, research to date does not define in sufficient detail the necessary fire regime to provide regeneration.

Attempts at determining the optimum fire regime have had limited success. Waldrop and Brose (1999) found that a high intensity fire was not necessary for successful regeneration of Table Mountain pine. While a lower-intensity fire is easier and safer to conduct, a medium-intensity fire was deemed to be best because it killed most of the overstory, which would allow sunlight to reach the soil surface. High-intensity fires led to the poorest regeneration success in that study. This may have been caused by combustion of cones or the high temperatures may have sterilized the upper soil which would have reduced minimally effective levels of mycorrhizal fungi. This study was conducted to determine the possible deleterious effects of high-intensity fire on ectomycorrhizae in Table Mountain pine seedlings.

METHODS

Study Area

The study area was the same as that used by Waldrop and Brose (1999) and was located in the Chattahoochee National Forest near Clayton, Georgia. Sites 1 and 2 were both 12 ha in size and at elevations of 914 and 884 m, respectively. Site 3 was 18 ha in size and was at 1100 m elevation. All three stands were similar in composition and stocking with an overstory of Table Mountain pine and understory of various hardwoods. Because of the previous lack of fire, the understory consisted of thickets of mountain laurel (*Kalmia latifolia*) and young hardwoods.

All three stands were burned as one unit on April 4, 1997, a total of 345 ha. Fire intensities within sample plots were classified by Waldrop and Brose (1999). Nine plots were classified as having been burned by low intensity fires, 28 as medium-low, 9 as medium-high, and 14 were high intensity. Site 3 burned at high and medium-high intensities and sites 1 and 2 burned at low and medium-high intensities.

Field Quantification of Mycorrhizae

Three months after the fire, 60 sample plots, 10x20 m^2 in size, were established throughout the three stands (Waldrop and Brose 1999). Four first- or second-year seedlings of Table Mountain pine were collected in October 1998 on the down-slope side of each of seven arbitrarily selected plots in site 1, eight plots in site 2, and seven plots in site 3. Seedlings were disinterred by carefully removing the attached soil ball and as much of the root system as possible. In the laboratory, each seedling was exposed to running tap water for two minutes to soften and remove soil particles. Seedling size was estimated by measuring stem length, tap root length, and length of lateral and short roots. Each root tip was visually inspected to determine presence of ectomycorrhizae. ANOVA and t-tests were conducted to compare seedling size and presence of mycorrhizae with plot location and seedling age.

Histology

After the preceding measurements were completed, representative root tips were severed and fixed in 3.5 percent glutaraldehyde, dehydrated, and embedded in plastic resin (JB-4 embedding kit, Fisher). Transverse sections 6-8 Fm thick were prepared using glass knives and a JB-4.3, JB-4A Porter Blum microtome. Sections were affixed to clean microscope slides, dried, stained with toluidine blue and

[1]Former Research Assistant, Department of Forest Resources, Clemson University, Clemson, SC; Research Forester, USDA Forest Service, Southern Research Station, 239 Lehotsky Hall, Clemson, SC; Emeritus Professor, Department of Forest Resources, Clemson University, Clemson, SC

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Statistics of Table Mountain pine seedlings from the field collections

Site	n	Mean Length (mm) Stem	Root	Total	Mycorrhizal Root tips
First-year seedlings					
1	2	8.5a[1]	5.3a	13.8a	7.0a
2	10	9.3a	6.5a	15.8a	25.0a
3	28	8.3a	9.4a	17.7a	20.0a
Second-year seedlings					
1	26	13.7a	8.7a	22.4a	42.5a
2	22	15.4a	10.1a	25.5a	36.7a

[1]Means with the same lowercase letter within a column are not significantly different at the 0.05 level.

safranin-fast green, and viewed under 100X magnification. Four sections from each root tip were examined and the following measurements were recorded: 1) mantel thickness and morphology, 2) diameter of cortical cells, and 3) morphology and diameter of intercellular hyphae. Comparison of these measurements with published data (Trappe 1962, Jackson and Mason 1984, Marx 1977, Hacskaylo 1961) indicated that *Cenococcum* spp., *Pisolithus tinctorius*, and *Suillus granulatus* were the most common symbionts of Table Mountain pine seedlings.

Axenic culture

In order to confirm that these species were, indeed, capable of forming ectomycorrhizae with Table Mountain pine, cultures of *Cenococcum graniforme*, *C. geophilum*, *P. tinctorius*, and *S. granulatus* were obtained from the American Type Culture Collection (Beltsville, MD). The cultures were maintained on Melin-Norkrans media.

Seeds of Table Mountain pine were surface disinfected by swirling in a 1 percent solution of sodium hypochlorite for three minutes, rinsed in three changes of sterile distilled water, and then plated on acidified potato-dextrose agar to test for surface sterility and to induce germination.

Axenic growth chambers consisted of 1-quart canning jars with a 1.27 cm dia piece of PVC pipe glued in a hole in the lid and plugged with cotton. The open end was covered loosely with a piece of aluminum foil to allow for aeration but to minimize dust contamination. Each jar contained a mixture of 400 ml of vermiculite and 256 ml of Melin's (1921) nutrient solution as modified by Norkrans (1949). The jars were autoclaved for 30 minutes at 121^0 C two separate times with a 24-hour period in between to allow for germination of heat-resistant spores. A layer of aluminum foil was wrapped around the bottom half of each jar to exclude light from the root zone. The jars were placed in a growth chamber programmed for an 18-hour photoperiod and a constant temperature of 22^0 C. Average light intensity was 21.83 microeinsteins (FE /sm^2).

An aseptic seed with a radicle 1-3 mm in length was transplanted into each jar at a depth of 6 mm. At the same time, 2-10 mm discs of inoculum from 30-day-old cultures of the respective fungus were placed on the vermiculite surface. After four months incubation, the seedlings were removed, measured as with the field quantifications, and inspected for mycorrhizal development.

The experiment included a total of 60 jars, with 5 treatments which included each of the four fungi and a control with only an aseptic seedling and 12 replications within each treatment. The entire experiment was performed twice. Results were analyzed by ANOVA and t-tests.

Heat treatments

A heated water bath was used to determine the resistance of mycorrhizal fungi to heat. Pure cultures of each of the respective mycorrhizal fungi were grown in 1-quart canning jars as described above, except that pine seedlings were not placed in the jars for the first part of the experiment. After 30 days incubation, the jars containing their respective fungal cultures were placed in a water bath at 25^0 C (control), 50^0 C, 60^0 C, or 80^0 C, respectively, for 60 minutes. After cooling for 24 hours, two aseptic seeds of Table Mountain pine each with a radicle 1-3 mm in length were planted in each jar. The jars were incubated for 90 days, after which time the seedlings were removed, measured as with the field quantifications, and inspected for mycorrhizal development. Sixty jars were used, separated into five sets of twelve each. Each set included the four fungi and a control. The experiment was repeated twice. ANOVA and t-tests were conducted.

RESULTS AND DISCUSSION

Field Quantification of Ectomycorrhizae

Sites 1 and 2 had burned with similar low- to medium-fire intensities whereas site 3 burned at a much higher intensity. Because of this, there was no difficulty in finding an adequate number of either first- or second-year

Table 2—Statistics of Table Mountain pine seedlings in axenic culture, in first/second experiments

Fungal Species	# of Seedlings	Total Length (mm)	# root tips (avg.)	# mycorrhizal root tips (avg.)
C. gran.	11/ 11	15.6a[1]/ 14.4a	56.6a/ 29.4a,b	0.6a/ 5.3b
C. geop.	12/ 12	21.4a/ 13.3a	45.8a,b/ 21.2a,b	3.8a/ 7.5b
S. gran.	10/ 10	28.2b/ 16.4a	52.2a,b/ 31.3a	4.5a/ 21.1a
P. tinc.	10/ 11	18.0a/ 13.2a	20.6c/ 13.6b	4.4a/ 7.6b
Control	11/	16.0a/	31.2b,c/	0.0a/

seedlings at the first two sites but it was very difficult to find either first- or second-year seedlings at site 3. Hence, only a limited number of first-year seedlings could be found and there are no second-year seedling data for site 3.

There was no significant difference in average stem length, root length, total length, and average number of root tips with mycorrhizae among first-year and second-year seedlings of Table Mountain pine between the study areas (table 1). However, there was a significant difference in mycorrhizal root tips between first- and second-year seedlings. Approximately 70 percent of the root tips from all three sites were mycorrhizal, suggesting that mycorrhizal development began in the first growing season after the fire and continued into the second season. The data also suggest that soil temperatures did not reach lethal levels, even with the high-intensity fire.

Table 3—Average number of mycorrhizal root tips formed at various temperatures and by different fungal species

Temperature (^{0}C)	Experiment 1	Experiment 2
25	6.1 a,b[1]	5.4 a
50	7.7 a	2.1 a,b
60	2.3 b,c	3.8 a,b
80	0.1 c	0.3 b
Fungus		
Control	0.0 b	0.0 b
C. geo.	0.0 b	0.9 b
C. gran.	1.7 b	1.1 b
S. gran.	8.9 a	5.8 a
P. tinct.	9.7 a	5.8 a

[1]In each experiment, means followed by the same lowercase letter are not significantly different at the 0.05 level.

Histology

There were three distinct morphological types of ectomycorrhizae observed on the roots of Table Mountain pine. These matched published descriptions of *Suillus granulatus*, *Pisolithus tinctorius*, and *Cenococcum* sp. (Chambers and Cairney 1999, Riffle 1973, Marx and others 1969). The most important diagnostic attributes were color, type of branching, root tip length and diameter, mantle diameter, presence of the hartig net, and size of cortical cell. Visual examination of mycorrhizal root tips and the histological sections indicated that *P. tinctorius* was the slightly more abundant of the three fungal symbionts in all three sites in both first- and second-year seedlings. The occurrence of mycorrhizal root tips on first-year seedlings in site 3 suggests that soil sterilization did not occur.

Axenic Culture

The two axenic culture experiments produced relatively low levels of mycorrhizal root tips and the results were somewhat variable (table 2). Total seedling length with any of the fungi did not differ significantly from the control except in the first experiment where total seedling length of 28.2 mm for *S. granulatus* was significantly greater than that for any of the other fungi or the control. In the first experiment, only seedlings with *C. graniforme* were associated with a larger number of root tips (56.6) than the control (31.2), yet this difference was not observed in the second experiment, nor was there any difference in the average number of mycorrhizal root tips between any of the fungi and the control. In the second experiment, only *S. granulatus* produced a significantly greater number of mycorrhizal root tips (21.1) than the control (0.0). Mycorrhizal fungi are notoriously difficult to work with in axenic culture and it is suspected that the low infection rates seen here are due to the lack of a clear understanding of all the subtle growth variables necessary for successful infection.

Heat Treatments

This experiment was conducted twice, with similar results produced both times. Hence, only the results of experiment one are presented. At the control temperature of 25^0 C, 74 percent of *S. granulatus* root tips were mycorrhizal, 49 percent of *P. tinctorius* root tips were mycorrhizal, 16 percent of *C. graniforme* root tips were mycorrhizal, and *C. geophilum* and sterile seedlings had no response (figure 1). The mean mycorrhizal count for all the fungal species was 6.1 per seedling.

At 50^0 C, 79 percent of *P. tinctorius* root tips were mycorrhizal, 75 percent of *S. granulatus* root tips were mycorrhizal, 10 percent of *C. graniforme* root tips were mycorrhizal, and *C. geophilum* and sterile seedlings had no response (figure 1). The mean mycorrhizal count for all the fungal species was 7.7 per seedling.

At 60^0 C, 31 percent of *P. tinctorius* root tips were mycorrhizal, 13 percent of *S. granulatus* root tips were

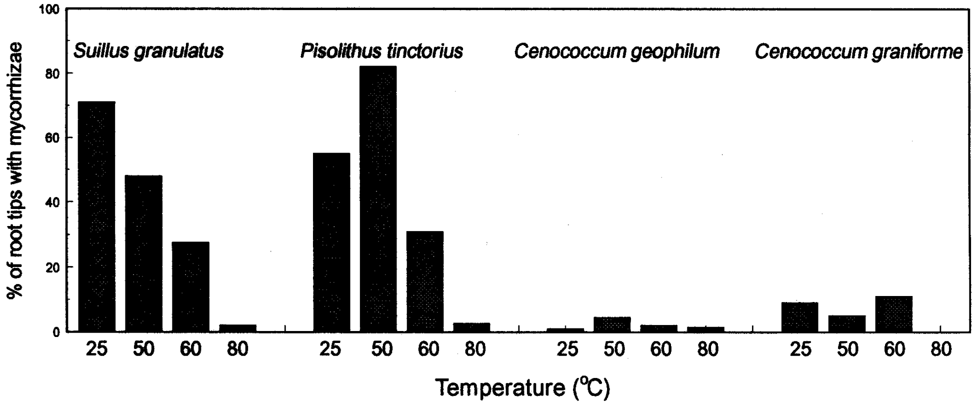


Figure 1—Percentage of Table Mountain root tips with mycorrhizae by fungal species formed after heat treatments at various temperatures.

mycorrhizal, and the two *Cenococcum* species and the control had no response (figure 1). The mean mycorrhizal count for all the fungal species was 2.3 per seedling.

At 80^0 C, there was almost no mycorrhizal growth (figure 1), with *S. granulatus*, *P. tinctorius*, and *C. geophilum* producing only 3 percent to 6 percent of mycorrhizal root tips. The mean mycorrhizal count for all the fungal species was 0.1 per seedling.

There was a significant difference in mycorrhizal count among the various temperatures (table 3). Mycorrhizal abundance tended to drop at temperatures over 50^0 C and was almost eliminated at 80^0 C. There was also a significant difference in mycorrhizal count among fungi, with both *P. tinctorius* and *S. granulatus* different from *C. graniforme* and *C. geophilum* as well as the control. *S. granulatus* and *P. tinctorius* gave the most favorable results in the heat treatment experiments (figure 1). Both species grew well at the lower temperatures and, except for some variation at 50^0 C in experiment 2, both fungi grew in the same relative temperature range. Neither survived well at temperatures reaching 80^0 C.

CONCLUSIONS

Table Mountain pine was confirmed to be symbiotic with at least three mycorrhizal fungi, all of which are known for their preference for dry habitats and, hence, are very well adapted to form beneficial relationships with Table Mountain pine. This research also showed experimentally that these fungi cannot survive a prolonged temperature exceeding 80^0 C. Regardless of fire intensity, it is unlikely that temperatures of 80^0 C would be achieved to any significant soil depth. In the experimental burned area exposed to a high-intensity fire, the behavior of mycorrhizal formation in first- and second-year seedlings suggests that the mycorrhizal fungi either survived the intense fire intensities or they recolonized the site quickly. While it is probably desirable to perform prescribed burns at something less than a medium-high intensity, it seems clear from the results of the present research that even a medium-high intensity probably does not seriously harm the mycorrhizal symbionts in the soil of the burned areas.

ACKNOWLEDGMENTS

Funding for the research described here was provided by the USDI/USDA, Forest Service Joint Fire Sciences Program.

REFERENCES

Chambers, S. M. and J. W. G. Cairney. 1999. *Pisolithus*. Ectomycorrhizal Fungi: Key Genera in Profile. New York: Springer, Inc:1-31.

Hacskaylo, E. 1961. Factors influencing mycorrhizal development in some cultural practices. Recent Advances in Botany 14: 1744-1748.

Jackson, R. A. and P. A. Mason. 1984. Mycorrhizae. The Camelot Press, Ltd., Great Britain. 60 p.

Marx, D. H. 1977. Tree host range and world distribution of the ectomycorrhizal fungus *Pisolithus tinctorius*. Canadian Journal of Microbiology 23: 217-223.

Marx, D. H., W. C. Bryan and C. B. Davey. 1969. Influence of temperature on aseptic synthesis of ectomycorrhizae by *Thelephora terrestris* and *Pisolithus tinctorius* on loblolly pine. Forest Science 16: 424-431.

Melin, E. 1921. Uber die Mykorrizen pilze von *Pinus sylvestris* L. und *Picea abies* (L.) Karst. Svensk. Bot. Tidskr.15: 192-203.

Norkrans, B. 1949. Some mycorrhizae-forming *Tricholoma* species. Svensk. Bot. Tidskr. 43: 485-490.

Riffle, J. W. 1973. Pure culture synthesis of ectomycorrhizae on *Pinus ponderosa* with species of *Amanita*, *Suillus*, and *Lacterius*. Forest Science. 19: 242-250.

Trappe, J. M. 1962. Fungus associates of ectotrophic mycorrhizae. Botanical Review 28: 538-606.

Van Lear, D. H. and T. A. Waldrop. 1989. History, use and effects of fire in the Southern Appalachians. Gen. Tech. Rept. SE-54: U.S. Department of Agriculture, Forest Service. 20 p.

Waldrop, T. A. and P. H. Brose. 1999. A comparison of fire intensity levels for stand replacement of Table Mountain pine (*Pinus pungens* Lamb.). Forest Ecology and Management 113: 155-166.

Zobel, D. B. 1969. Factors affecting the distribution of *Pinus pungens*, an Appalachian endemic. Ecological Monographs 39: 303-333.

PRESCRIBED FIRE IN THE INTERFACE: SEPARATING THE PEOPLE FROM THE TREES

David T. Butry, John M. Pye, and Jeffrey P. Prestemon[1]

Abstract—Land managers in Florida rely on prescribed fire to prepare sites for regeneration, improve wildlife habitats, reduce vegetative competition, facilitate timber management activities, and mitigate wildfire risk. More than one million acres of land is scheduled for prescribed fire each year in Florida, nearly five times more than the area burned by wildfires. However, little has been done to understand the characteristics of communities affected by fire: who live in these communities and where are they located, where could additional prescribed burning and other wildfire risk mitigation activities be targeted, and how might continued population growth affect future tolerance for these practices? To shed light on these questions we use GIS overlay and correlation techniques to characterize and compare fire-affected zones in Florida. Characteristics studied include: population demographics, road density, neighborhood forest stand attributes, amount of forest fragmentation, and sources and frequency of wildfire ignition. We find that prescribed burning occurs in places where, on average, people are younger, earn lower incomes, have less formal education, are more frequently Caucasian, and live in more rural areas than people living in places without any prescribed fire or wildfire. High rates of prescribed burning occur in areas with less fragmented forests, more government management, and greater dominance by pine (Pinus spp.) forest types. Wildfires, on the other hand, occur most often in areas where forests are fragmented, ecologically more diverse, and privately owned.

INTRODUCTION

Prescribed fire is used extensively in Florida. Silvicultural burn permits were issued for roughly 500,000 acres a year from 1993 to 1999. Since 1981 wildfires on average have accounted for an additional 200,000 burned acres each year, as severe or catastrophic years (those totaling in excess of 400,000 acres) occur every four or five years. Since prescribed burning and wildfire are not uniformly distributed across the state (figures 1 and 2), residents' experiences with fire are likely to vary depending on where they live. Florida, with almost 16 million people in 2000, is the fourth most populous state in the U.S., and its population grew nearly 24 percent during the 1990's. Much of this population growth is due to a large influx of retirees, immigrants, and other northern migrants. Coupled with the state's large seasonal population, many Floridians may be quite new to wildfires, not to mention its large prescribed burning program. Such unfamiliarity, combined with high populations in certain locations, may result in new and greater constraints on wildfire risk reduction strategies, thereby resulting in greater risks of wildfire.

The purpose of this paper is to examine the people of Florida's wildland-urban interface, areas with a mix of people, development, and wildlands, and the fire-prone landscape in which they reside. We characterize where wildfires and prescribed fires occur and the relationships between where fires are found and whom they affect. The state of Florida provides an excellent study area with its diverse and growing population scattered among landscapes that frequently burn.

DATA

Our analysis combines six datasets: two from the Florida Division of Forestry (FDF), and the others from publicly available Census, USDA Forest Service, and remote sensing products.

Wildfires

The first FDF dataset provides information on all wildfire incidents reported to the State including the date of incident, number of acres burned, the ignition source, and the township, range, and cadastral section in which it occurred. Ignition sources include lightning, arson, and several other human-caused ignitions, which we grouped as accidents. These data span the calendar years 1981 to 1999 and do not include fires on federal lands.

Prescribed burning

In order to start a prescribed fire in Florida, a permit must be obtained from the State less than one day in advance. Records for each fire permit include the date of issuance, number of acres to be treated, location of at least one section of the prescribed burn, and the reason for the burn. Reasons include hazard reduction, disease control, site preparation for seeding or planting, wildlife habitat enhancement, and others. We group the reasons into two different types: seed and site prep (prior to seed and site prep) and traditional (everything else). The data span calendar years 1989 to 1999, although full statewide coverage did not begin until 1993.

[1]Economist, Ecologist, Research Forester, Disturbance Economics Research Team, USDA Forest Service, Southern Research Station, P.O. Box 12254, Research Triangle Park, NC 27709, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Demographics

The US Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) 1995 data from the Environmental System Research Institute (ESRI), describe population, race, age, education, income, and home value by Census block-group for the 1990 Census. We also obtained from ESRI the TIGER/line road coverage.

Fragmentation

A 30-meter resolution forest fragmentation grid coverage, derived from the Multi-Resolution Land Characteristics (MRLC) Consortium's land cover map, was obtained from the USDA Forest Service (see Riitters and others 1997). These data are used to classify Florida into 6 fragmentation classes based on percent forest cover and percent of forest connectivity: interior forest, edge forest, perforated forest, transitional forest, patch forest, and no forest (figure 3).

Interior forests have 100 percent forest cover and forest connectivity. Perforated and edge forests have high levels of forest cover (greater than 60 percent), but differ in their levels of forest connectivity (ranging from 0 to 100 percent). For the same level of forest cover, the edge forest has a higher level of forest connectivity, whereas, for the same level of forest connectivity, the perforated forest has more forest cover.

Transitional and patch forests can both have any level of connectivity (ranging from 0 to 100 percent), but are differentiated by their levels of forest cover. Transitional forests have between 30 to 60 percent forest cover, whereas patch forest have between 0 to 30 percent forest cover.

Forest Ownership and Type

Stand level characteristics were obtained from the plot records of Florida's 1995 Multiple Resource (MR) database, maintained by the USDA Forest Service's Forest Inventory and Analysis (FIA) unit in Asheville, NC. We use the plot ownership and forest type variables.

METHODS

First, we relate the aggregated number of burn permits issued by cadastral section to the number of wildfire ignitions by source for the "fire years" 1993 to 1999. Since the fire year runs from October 1 to September 30, fire year 1993 encompasses October 1, 1992, to September 30, 1993.

Second, we create a cadastral section road density measure consisting of all State, Interstate, and US highways in the section, divided by the area (in acres) of the section. The road density measure, along with the section burn permit and wildfire records, is rasterized into a 30-meter cell grid, the same as the forest fragmentation index. The burn permit and wildfire records are then compared with road density and the forest fragmentation index.

Third, we examine the FIA 1995 plot survey data (point analysis) to relate the plot's forest ownership and forest type to the incidence of prescribed fire, wildfire, or no fire since the previous FIA survey (1987).

Fourth, we aggregate the Census TIGER block-group to the section level using a Geographic Information System (GIS), enabling us to observe the demographic attributes of those communities residing within a section (approximately a one square mile neighborhood) and observe how demographics vary with different levels of prescribed burning and wildfire.

RESULTS

The most intense areas of prescribed burning appear to be in the north central and panhandle regions of Florida (figure 1), while wildfire ignitions occur more evenly throughout Florida, most heavily in the southwestern region (figure 2). A negative relationship exists between the number of burn permits issued and the number of wildfire ignitions, regardless of the ignition source (table 1). Of the cadastral sections examined, only half (52 percent) of the Florida landscape escaped all fire (prescribed or wild) for the periods covered. However, this may be an overestimation since our data only specified one section for each burn permit and wildfire (the section it started in), and fires may span multiple sections. Approximately 75 percent of wildfire ignitions occur in sections without a record of any prescribed burning. Areas that average no more than one burn permit a year experience another 21 percent of the ignitions, with the remaining 4 percent occurring in areas with more than one permit a year.

Prescribed fire occurs more frequently on government owned (federal, state, and local) and managed forest, than on forests owned by industry or private landowner. Consistent with these statistics is that the most common forest type prescribed burned is slash pine (*Pinus elliottii*) (FIA analysis, table 2), a species widely planted and managed in the state.

Table 1—Number of prescribed burns and wildfires occurring in a township, range, section

PB Permits in a Section	Arson Ignitions	Accidents Ignititions	Lightning Ignitions	Number of Possible Sections
None	4,510	11,006	4,355	33,264
1 to 7	1,534	3,993	1,193	9,362
8 to14	171	538	100	1,067
15 to 21	52	177	31	321
>21	59	186	27	308
All (>0)	1,816	4,894	1,351	11,058

Table 2—Percent of fire disturbance type by Forest Inventory and Analysis (FIA) plot ownership and forest- type

Type of Fire Disturbance	Gov't	Forest Industry	Private	Predominant Forest Type (pct)
Prescribed Burned	59	14	23	Slash Pine (49)
Wildfire	19	8	49	Baldcypress-Water Tupelo (32)
No Fire Disturbance	29	26	52	Slash Pine (33)

Table 3—Percent of prescribed burning and wildfire found in each forest fragmentation type

Fragmentation	Prescribed Burned?		Burned by Wildfire?	
Type	Yes	No	Yes	No
Interior	18	12	11	17
Edge	15	9	17	15
Perforated	19	12	13	11
Transitional	19	22	10	8
Patch	21	27	33	28
No Forest	7	16	14	18
Total	99	98	98	97

Table 4—Demographic comparison between areas without fire and those with either prescribed burning or wildfire

Demographics	PB& No Fire	Wildfire& No PB	Any Fire& Burn	No Fire& Burn
Pop. Density	0.08	0.41	0.11	0.55
55&Over (pct)	23	26	24	25
Not Caucasian (pct)	19	17	15	21
No College (pct)	46	44	46	45
House Value ($)	8,202	12,220	8,702	10,532
Income ($)	9,431	10,595	9,613	10,102

House value and income given as per capita, in 1990 dollars. Population Density given as persons per acre.

Table 5—Demographic comparison between areas with any prescribed burning categories 'traditional' and 'seed & site prep' in the neighborhood

Demographics	Traditional Burn	Seed & Site Prep Burn
Pop. Density	0.10	0.06
55&Over (pct)	24	23
Not Caucasian (pct)	19	16
No College (pct)	45	47
House Value ($)	10,755	10,723
Income ($)	10,182	10,148

House value and income given as per capita, in 1990 dollars.
Population given as persons per acre.

Table 6—Demographic comparison between areas with any wildfire ignition categories arson, accidental, and lightning in the neighborhood

Demographics	Arson Wildfire	Accidental Wildfire	Lightning Wildfire
Pop. Density	0.38	0.37	0.19
55&Over (pct)	26	25	27
Not Caucasian (pct)	15	17	14
No College (pct)	45	45	45
House Value ($)	11,003	10,417	13,713
Income ($)	10,200	10,143	10,874

House value and income given as per capita, in 1990 dollars. Population density given as persons per acre.

The landscape composition of wildfire-prone forests differs from those with prescribed burning. Almost half of the FIA plots reporting wildfire are privately owned. In contrast to the pine-dominated areas with prescribed burning, FIA plots with wildfire are dominated by the baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) forest type (32 percent, table 2). Furthermore, wildfires ignitions appear to occur most often in the patch fragmentation class, those forests with less cover and connectivity (table 3). Road density is also two times higher in these wildfire prone regions.

Demographic differences are correlated with the amount of wildfire or prescribed burning. Table 4 shows that population density is lower in areas with fire than without (0.11 persons/acre versus 0.55 persons/acre, respectively). Areas with prescribed burning or wildfires have populations that are, on average, slightly younger, more likely to be Caucasian, and wealthier than areas without any fire (prescribed fire or wildfire). However, neighborhood differences exist between areas with prescribed fire only and those with wildfire only. Areas with wildfire and no prescribed burning tend to be more densely populated, have a larger proportion of older Floridians, and have higher per capita income and home values.

Examining prescribed fire by management objective (traditional burns versus site prep/prior-to-seed burns), we do not observe any striking difference (table 5), but distinguishing areas by wildfire ignition source, regardless of whether prescribed burning exists in that area or not, reveals a couple of differences. Compared to areas without wildfires, lightning ignitions tend to occur in sparsely populated, predominantly Caucasian neighborhoods (table 6). Also, lightning ignition appears to happen in wealthier neighborhoods, whereas arson and accidental ignitions tend to occur in lower income, more populated neighborhoods.

CONCLUSION

Florida's fire-prone wildland-urban interface is quite different, both physically and socio-economically, from areas without fire (prescribed fire and wildfire). Areas with high rates of prescribed burning are more commonly slash pine forests under government ownership, and these areas have much lower rates of wildfire ignitions.

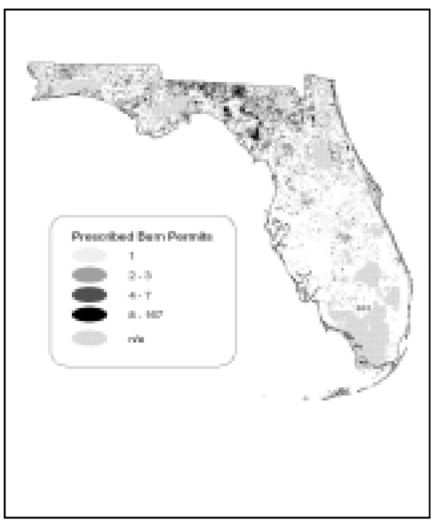


Figure 1—Number of prescribed burn permits issued from fire years (October-September) 1993-1999. Federal lands excluded.

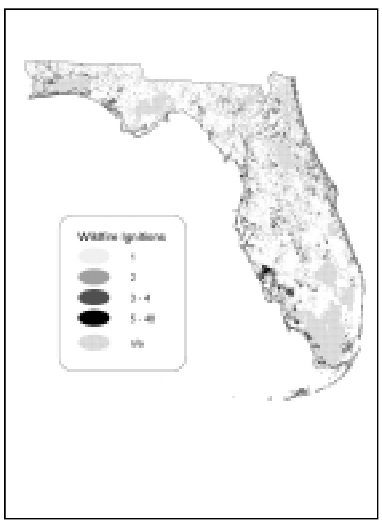


Figure 2—Number of wildfire ignitions from fire years (October-September) 1993-1999. Federal lands excluded.

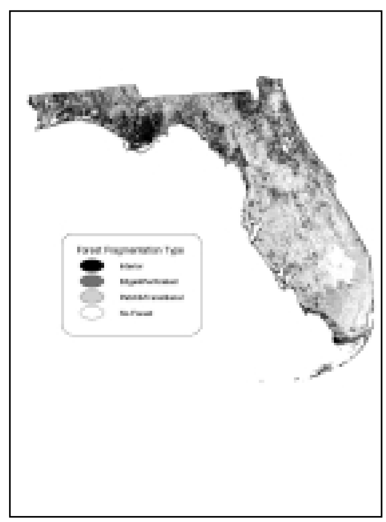


Figure 3—Forest fragmentation index, 1992

Government land managers may use prescribed fire, more so than private land managers, for a numbers of reasons including that governments maintain large land holdings, have greater expertise with prescribed fire, and are more likely to operate under policies to maintain the health of fire adapted ecosystems. Liability concerns over possible prescribed fire escapes may deter private landowners from using it, perhaps inducing them to use other types of fuel reduction techniques. Forests frequented by wildfires, however, tend to be privately owned, dominated by baldcypress-water tupelo, and have relatively less forest cover and lower forest connectivity than their prescribed burning neighbors. Reducing wildfire risk in baldcypress-water tupelo stands may be difficult given their close association with open water. However, drought condition may be severe enough to dry out these areas, leaving the baldcypress stands susceptible to wildfire, as seen during the catastrophic fires of 1998 (Mercer and others 2000).

The residents of those parts of Florida where fire is more common are, on average, more likely to be Caucasian, older, less educated, and earning lower incomes than those living in less risky areas. However, there is a marked difference between those living in places that experience prescribed burning and no wildfire, and those living in areas with wildfires and no prescribed burning. Those living in wildfire areas tend to be older, more often Caucasian, and wealthier than those with only prescribed fires, and this is particularly true for wildfires started by lightning. These differences may highlight the reasons people choose to live within the wildland-urban interface in the first place. Many people choose the interface for its amenities, while others, especially the retired and the poor, base their decision on economic criteria (Davis 1990). Prescribed burning may serve as a proxy for intensively managed forestlands, which may offer fewer amenity benefits, creating lower land prices, and thereby attracting those with lower incomes. Wildfire-prone areas without prescribed burning, on the other hand, may provide greater amenity benefits over areas without fire, providing benefits such as greater forest access than prescribed burned areas, providing benefits such as less smoke and a feeling of a more 'natural', undisturbed forest (less active management). Differences may also be related to differences in forest types. Many of these unmanaged wildfire-prone forests may be baldcypress-tupelo forests, located on more valuable properties near water. This would help account for the income and housing value differences between prescribed burned and wildfire only areas.

With Florida's continuing population growth, more and more people are moving into the wildland-urban interface and creating greater challenges for policymakers and land managers to reduce wildfire risk. Since catastrophic fires can produce large economic effects (Mercer and others 2000, Butry and others 2001), successful risk reduction programs can reap great dividends. However, populations either unaccustomed to prescribed fire or those with compromised respiratory health may be opposed to the use of fire and the resulting smoke. These attitude can be changed however, as Cortner and others (1990) found attitudes towards fire management have been changing over the last few decades. Indeed, demographic analyses such as these may help land managers and educators better target prescribed fire and wildfire education programs, potentially easing some concerns of residents. Alternatively, identification of such populations could facilitate the development and targeted application of wildfire risk reduction strategies that do not involve prescribed fire or that encourage such burning in times of the year when residents are least affected.

ACKNOWLEDGMENTS

We would like to thank Annie Hermansen and Evan Mercer for their comments, suggestions, and insights.

LITERATURE CITED

Butry, D.T.; Mercer, D.E.; Prestemon, J.P.; Pye, J.M.; Holmes, T.P. 2001. What is the price of catastrophic wildfire? Working Paper. Forestry Science Laboratory, Southern Research Station, USDA Forest Service, Research Triangle Park, NC.

Cortner, H.J.; Gardner, P.D.; Taylor, J.G. 1990. Fire hazards at the urban-wildland interface: what the public expects. Environmental Management 14(1): 57-62.

Davis, J.B. 1990. The wildland-urban interface: paradise or battleground? Journal of Forestry. January 1990: 26-31.

Mercer, D. E.; J.M. Pye; J.P. Prestemon; D.T. Butry; T.P. Holmes. 2000. Economic effects of catastrophic wildfires. Unpublished final report. Forestry Sciences Laboratory, Southern Research Station, USDA Forest Service, Research Triangle Park, NC. http://www.rtp.srs.fs.fed.us/econ/pubs/dem001.htm

Riitters; K.H., O'Neil; R.V.; Jones, K.S. 1997. Assessing habitat suitability at multiple scales: a landscape-level approach. Biological Conservation 81: 191-202.

HIGH-INTENSITY FIRES MAY BE UNNECESSARY FOR STAND REPLACEMENT OF TABLE MOUNTAIN PINE: AN OVERVIEW OF CURRENT RESEARCH

Thomas A. Waldrop, Patrick H. Brose, Nicole Turrill Welch, Helen H. Mohr, Ellen A. Gray, Frank H. Tainter, and Lisa E. Ellis[1]

Abstract—After several decades of fire suppression, ridgetop pine communities of the Southern Appalachians are entering later seral stages and beginning to disappear. They typically have an overstory of Table Mountain pine (*Pinus pungens*), which is being replaced by shade-tolerant chestnut oaks (*Quercus prinus*). Previous papers suggest that high-intensity fires that open the forest canopy and expose mineral soil can restore these communities. Three recent studies examined plant-community response to prescribed fires of varying intensity. Four supporting studies help explain some of the results of these field studies. High and medium-high intensity fires provided adequate sunlight for pine seedlings, whereas medium-low and low intensity fires did not. Sufficient seedling densities to restore pine-dominated stands were present after all but the highest intensity fires. High-intensity fires may have reduced mycorrhizal abundance and moisture availability for new germinants. Fires of lower intensity than previously recommended or multiple fires of very low-intensity may best provide conditions for pine regeneration.

INTRODUCTION

Fire exclusion policies in the Southern Appalachian Mountains probably have reduced the diversity of the region and may threaten some plants and plant communities (Van Lear and Waldrop 1989). A species of concern is Table Mountain pine (*Pinus pungens* Lamb.). This Appalachian endemic has serotinous cones throughout its range, suggesting that fire may be needed for regeneration (Zobel 1969). Microsite conditions needed for seedling establishment, such as high levels of sunlight and little or no forest floor, are similar to those created by high-intensity fire. Table Mountain pine stands throughout the region are entering late seral stages and are often characterized as being dominated by oaks (particularly chestnut oak, *Quercus prinus*) and hickories (*Carya* sp.) (Zobel 1969). As a result of changing species dominance and stand structure, the Southern Appalachian Assessment recognizes Table Mountain pine woodlands as one of 31 rare communities (SAMAB 1996).

Most research addressing the role of fire in Table Mountain pine stands has been limited to post-wildfire studies, which suggest that high-intensity prescribed fires are needed to remove the forest canopy and expose mineral soil for successful regeneration (Zobel, 1969, Williams and Johnson 1992). Williams (1998) suggested that Table Mountain pine stands are in decline as a result of fire exclusion and inadequate understanding of the species regeneration biology.

High-intensity, stand-replacement prescribed burning may reverse the decline. However, accomplishing these burns is difficult. Such prescriptions provide a narrow window of opportunity and raise questions about worker safety and smoke management. To date, only three studies have conducted prescribed burns to better understand the conditions necessary for Table Mountain pine regeneration. This paper examines the results of the three prescribed fire studies and four supporting studies of regeneration ecology to evaluate the need for high-intensity, stand replacement fires for regenerating Table Mountain pine.

CURRENT RESEARCH ON STAND-REPLACEMENT PRESCRIBED BURNING

Studies of stand-replacement prescribed burning were conducted at three separate burn units in the southern Appalachian mountains, including the Grandfather Ranger District, Pisgah National Forest; Tallulah Ranger District, Chattahoochee National Forest; and a burn unit managed by both the Andrew Pickens Ranger District, Sumter National Forest and the Buzzard's Roost Preserve of the South Carolina Heritage Trust Program. In this paper, we refer to these burn units as the Grandfather, Tallulah, and Buzzard's Roost burns, respectively. Welch and others (2000) described the Grandfather burn. Waldrop and Brose (1999) described the Tallulah burn.

Several supporting studies provide insight to disturbance history and methods of evaluating stands for their potential of regeneration success. Waldrop and others (1999) conducted a greenhouse study to evaluate the effects of

[1]Research Forester, USDA Forest Service, Southern Research Station, Clemson, SC; Research Foreseter, USDA Forest Service, Northeastern Research Station, Warren, PA; Graduate Student, School of Public and Environmental Affairs, Indiana University, Bloomington, IN; Graduate Students, Clemson University, Department of Forest Resources, Clemson, SC; Professor, Graduate Student, Department of Forestry, Wildlife and Fisheries, University of Tennessee, Knoxville, TN, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Characteristics of Table Mountain pine stands one year following stand-replacement prescribed burning

Variable	Fire Intensity Level: Low	Med-Low	Med-High	High	Fire
Pine basal	5.9	6.0	1.1	0.0	Tallulah[1]
area (m²/ha)	8.4	6.4	0.0		Buzzard's Roost
		21.6			Grandfather[2]
Hardwood	16.8	5.1	0.5	1.0	Tallulah
basal area	11.8	4.2	7.6		Buzzard's Roost
(m²/ha)		4.3			Grandfather
Total basal	22.7	11.1	1.6	1.0	Tallulah
area (m²/ha)	19.2	10.8	7.6		Buzzard's Roost
		25.9			Grandfather
Hardwood	32,150.0	37,371.0	26,590.0	31,537.0	Tallulah
sprouts	20,553.0	25,582.0	17,505.0		Buzzard's Roost
(num/ha)		2,295.0			Grandfather
Pine seedlings	13,852.0	22,551.0	9,016.0	3,448.0	Tallulah
(num/ha)	551.0	995.0	961.0		Buzzard's Roost
		7,699.0			Grandfather

[1]Waldrop and Brose (1999)
[2]Welch and others (2000)

shade and duff on seedling establishment. Other studies include the dendrochronology of ridgetop pine stands across the Southern Appalachians (Brose and others 2002), seed biology of Table Mountain pine (Gray and others 2002), and mycorrhizal associations in burned Table Mountain pine stands (Ellis and others 2002). We will discuss results from each.

Fire Intensity and Stand Replacement of Table Mountain Pine

The Tallulah burn was on the War Woman Wildlife Management Area of the Tallulah Ranger District, Chattahoochee National Forest in north Georgia. Prior to burning, mean total basal area in study stands was 28.2 m^2 per ha. Hardwoods made up 22.7 m^2 of this total and Table Mountain pines the remaining 5.5 m^2. The fire was ignited by hand and by helicopter in April 1997 to create a ring fire that reached greatest intensity within ridgetop Table Mountain pine stands. The Tallulah burn was large enough and its intensity varied enough to allow comparisons of regeneration success among areas burned at different intensities (Waldrop and Brose 1999).

The Buzzard's Roost Burn was on a tract of approximately 100 ha managed by the South Carolina Heritage Trust Program and 45 ha managed by the Andrew Pickens Ranger District, Sumter National Forest. Prior to burning, stand basal area was 10.9 m^2 per ha hardwoods and 10.1 m^2 pine. Ignition was by helicopter on March 4, 1998. Fire intensity ranged from subcanopy ground fires to flame lengths reaching the lower levels of the stand canopy.

The Grandfather burn was a 3-ha prescribed fire on the Grandfather Ranger District, Pisgah National Forest. Basal area consisted of 8.7 m^2 per ha in hardwoods and 23.6 m^2 per ha in pines. Ground crews used a combined ring and head fire technique to burn the stand in May 1996. Flames reached to lower limbs on most trees and entered the canopy on a small portion of the stand.

The prescriptions applied in these studies produced four fire intensities defined by Waldrop and Brose (1999): low, medium-low, medium-high, and high. All intensities were observed in the Tallulah burn and all but high intensity was observed in the Buzzard's Roost burn. At the Grandfather burn, only the medium-low intensity was observed. Waldrop and Brose (1999) gave a detailed description of how fire intensity was classified using discriminant functions. General descriptions of intensity categories are as follows: Flames of low intensity fires never reached into the crown of trees and uniformly burned the area. Medium-low-intensity fires had flames slightly taller than those of low-intensity fire; they burned less uniformly and produced hot spots where flames reached into crowns and killed large trees. Flames of medium-high intensity fires typically reached into the crowns of all overstory trees. Flames of high-intensity fires generally exceeded the crowns of overstory trees and carried from crown to crown.

High-intensity fires occurred only in the Tallulah burn where they killed almost all overstory trees, leaving only 1.0 m^2 of basal area per ha (table 1). Medium-high intensity fires occurred at Tallulah and Buzzard's Roost. These fires were also effective for killing overstory trees, leaving only 1.6 and 7.6 m^2 per ha of basal area, respectively. Mortality was high in all diameter size classes following both high- and medium-high-intensity fires. Sunlight reaching the forest floor may have been adequate for seedling survival following fires of both intensities. High- and medium-high intensity fire were the only ones of sufficient intensity to kill enough of the overstory to achieve conditions of stand replacement.

In all three studies, medium-low- and low-intensity fires reduced canopy cover (table 1), but residual basal area may have been too high to allow stand replacement. At the Tallulah burn, medium-low-intensity fires reduced basal area to 11.1 m^2 per ha and 10.8 m^2 per ha at the Buzzard's Roost burn, but left 25.9 m^2 per ha at the Grandfather burn. Low-intensity fires had little effect on basal area, leaving 22.7m^2 per ha at the Tallulah burn and 19.2 m^2 at the Buzzard's Roost burn. Mortality was greatest in lower d.b.h. classes (< 15 cm d.b.h.) following fires of medium-low and low-intensity. Shade from surviving trees after low- and medium-low intensity fires may prevent pine seedling survival.

We observed prolific hardwood sprouting following fires of all intensities (table 1). Generally, there were over 20,000 stems per ha one year after burning at all fire intensities. Most were growing rapidly. Competition from these sprouts may eliminate any pine regeneration after a fire of any fire intensity. This result suggests that multiple, low-intensity fires may be necessary to reduce hardwood abundance while maintaining a seed source among large pines.

Post-burn counts of Table Mountain pine seedlings in the Tallulah and Grandfather burns suggest that fires were of sufficient intensity to open serotinous cones throughout burn units, even in areas burned at low-intensity. In these two units, post-burn pine density ranged from 3,448 to more than 22,500 stems per ha (table 1). An unexpected result was that the lowest pine densities in the Tallulah burn were in areas burned at the highest intensity. This suggests that cones were consumed or seeds killed by intense heat, or that the seedbed became less suitable by excessive exposure to sunlight and evaporation.

Table Mountain pine regeneration was poor at all fire intensities in the Buzzard's Roost burn. A number of factors could cause poor regeneration success, including thick residual duff or lack of viable seed. Duff layers after burning at Buzzard's Roost averaged only 4.4 cm deep and did not vary by fire intensity. Duff remaining after the Tallulah burn was generally deeper with 5.3, 3.8, 6.4, and 6.6 cm for the low-, medium-low-, medium-high-, and high-intensity fires, respectively. The percentage of seedlings with roots penetrating mineral soil at Tallulah was 71.1, 94.6, 63.0, and 56.1 for the same order of fire intensities (Waldrop and Brose 1999). Welch and others (2000) observed pine regeneration on approximately 9.1 cm of combined litter and duff after the Grandfather burn. Successful regeneration of Table Mountain pine on the thicker duff layers found in the Tallulah and Grandfather burns may indicate that lower availability of viable seed caused low regeneration counts at the Buzzard's Roost burn. Methods for estimating seed viability prior to burning are currently unavailable for Table Mountain pine stands.

Supporting Studies

Seed biology—In the past, studies of prescribed burning assumed an adequate seed source that did not vary among stands or stand conditions. Any regeneration failures could have been caused by an inadequate seed source. An ongoing study by Gray and others (2002) helps identify stands that have an adequate seed source for regeneration. Preliminary results indicate that seed viability was moderate, generally between 20 and 50 percent, from cones of all ages, and from trees older than 10 years (table 2). Viability did not appear to vary by age after trees reached 10 years. However, viability seemed to increase as cones matured to 4 or 5 years old. These results indicate that, if cone numbers are adequate, stands over a wide range of ages may be candidates for burning. A surprising result is the presence of cones with viable seed on young trees. Trees within the 5- to 10-year age class had 3-year-old cones with 23 percent seed viability. This result suggests that Table Mountain pines are adapted to regenerating under regimes of low-intensity fires, which may occur every 5 to 10 years. These results also indicate that if frequent low-intensity fires are used, that viable seed will become available every 2 to 3 years as long as fires do not kill overstory pines.

Table 2—Percent viability of Table Mountain pine seed by tree age and cone age within a tree

	Cone Age				
Tree age class	2 years	3 years	4 years	5 years	All Ages
5 to 10 years	8	23	1	-	-
11 to 25 years	20	32	41	23	27
26 to 50 years	33	11	24	56	31
51 to 75 years	29	20	34	36	30
75+ years	29	13	54	39	33
All tree age classes		24	21	34	36

Seedbed habitat—In order to assess seedling establishment, Waldrop and others (1999) conducted a greenhouse study that used shade and duff treatment combinations similar to those observed in the field. Duff categories included depths of 0, 5, and 10 cm; and shade levels of 0, 30, 63, and 85 percent. Figure 1 shows the total number of seedlings per plot in all combinations of duff and shade at the end of the 90-day greenhouse study. Stem density typically was greater in 5-cm duff than in bare soil or 10-cm duff. This pattern remained constant for all shade categories except the 0-shade category. In 0 shade, stem densities in pots with 5 cm of duff were equal to stem densities in pots without duff. Without shade, the mulching effect of a 5-cm duff layer may not have been adequate to prevent moisture deficit and seedling death.

Lack of shade reduced seed germination and the survival of germinants, while heavy shade reduced survival. More seedlings become established under 30-percent shade than under full light or the higher shade levels. This pattern was constant among pots with 5 and 10 cm of duff, but differed among pots with no duff (figure 1). With no duff, fewer seedlings per pot occurred under 30-percent shade than under no shade, although this difference was not

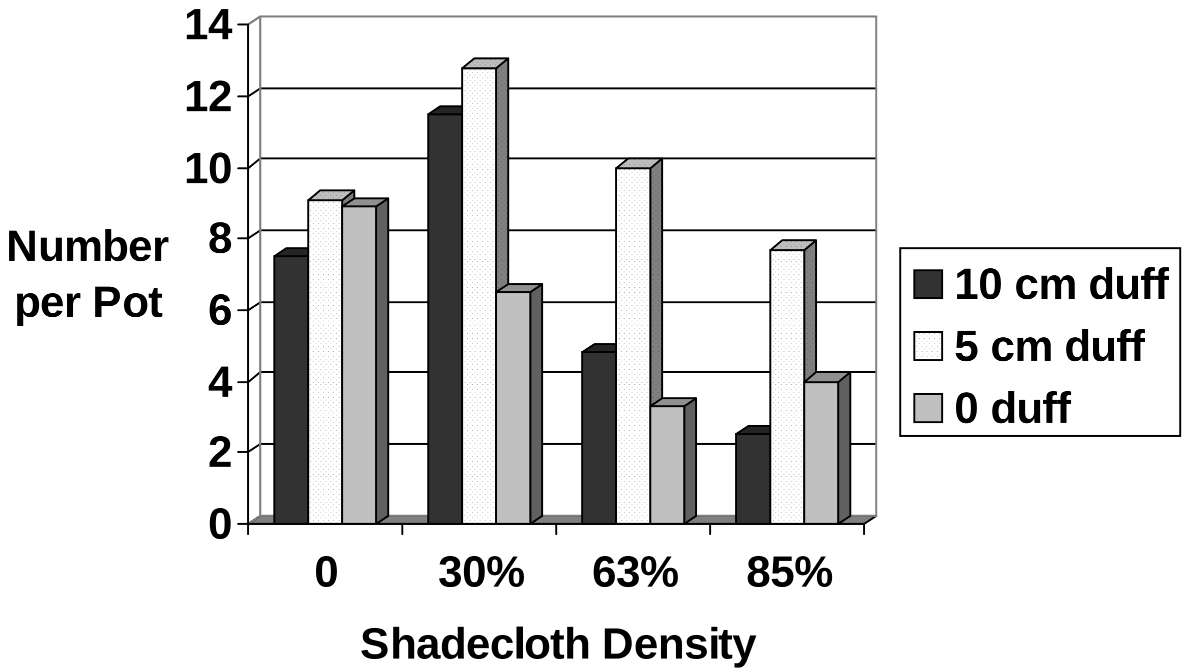


Figure 1—Seedlings per pot after the 90-day greenhouse study for all combinations of shade level and duff depth.

significant. Without the mulching effect of duff, 30-percent shade may not be adequate to prevent moisture deficit.

The moderate levels of shade and duff, suggested by this study as optimum seedbed habitat, differ somewhat from previous recommendations. Although the exact fire regimes necessary to create this type of habitat are unknown, these results do not suggest that a single high-intensity fire is mandatory. Multiple lower-intensity fires can maintain an overstory and seed source and reduce the duff without exposing mineral soil.

Fire Intensity and Mycorrhizae—The need for mycorrhizae is generally accepted for southern pine seedlings grown in nurseries, but it has not been studied for nontimber species such as Table Mountain pine. Neary and others (2000) suggested that fire intensity strongly affects the degree and duration of reduced soil microbial activity. An ongoing study by Ellis and others (2002) examines the relationship of fire intensity to mycorrhizal development on Table Mountain pine roots. Preliminary results indicate that *Pisolithus tinctorius*, *Suillus granulatus*, and *Cenococcum* spp. are the predominant symbionts that form mycorrhizal root tips in Table Mountain pine stands. Two years after burning, seedlings growing in areas burned at medium-low and medium-high fire intensities had twice as many mycorrhizal root tips (40 percent) than seedlings from sites burned at high intensities (22 percent), indicating a lasting negative impact of high-intensity prescribed fires. Laboratory results were similar, showing that mycorrhizal roots tips are less common after fungi have been exposed to temperatures over 50°C and almost absent after exposure to temperatures up to 80°C. These results suggest that poor formation of mycorrhizal root tips could have caused poor regeneration of Table Mountain pine in the Tallulah burn after high-intensity burning. Frequent low-intensity burning would be one means of avoiding loss of mycorrhizal fungi.

Dendrochronology—Little is known about the disturbance history of Table Mountain pine stands. The species may have been maintained by frequent low- to medium-intensity fires, infrequent high-intensity stand-replacing fires, or a combination of both. Brose and others (2002) conducted a dendrochronology study on the Tallulah, Buzzard's Roost, and other sites. A preliminary analysis of stand dynamics suggests a history of frequent disturbance that lasted until the 1950's (figure 2). Pines in the dominant canopy position are between 100 and 158 years old. However, numerous smaller pines are between 50 and 100 years old. Shrubs, particularly mountain laurel, are less than 50 years old, and there are no pines younger than 50 years. The frequency pattern of pine age classes indicates that pines were regenerating from the 1850's through the 1950's, and that these stands were relatively open. Well-established fire exclusion policies in the 1950's allowed the shrub layer to become dominant and prevented continuing pine regeneration. Successful restoration of these stands cannot be expected with a single prescribed burn of any intensity. Multiple burns or other control methods will be required to remove shrubs and competing hardwoods.

CONCLUSIONS

High-intensity fires are attractive for a number of reasons: they provide a means of killing overstory trees and opening the forest floor to direct sunlight; they provide the heat

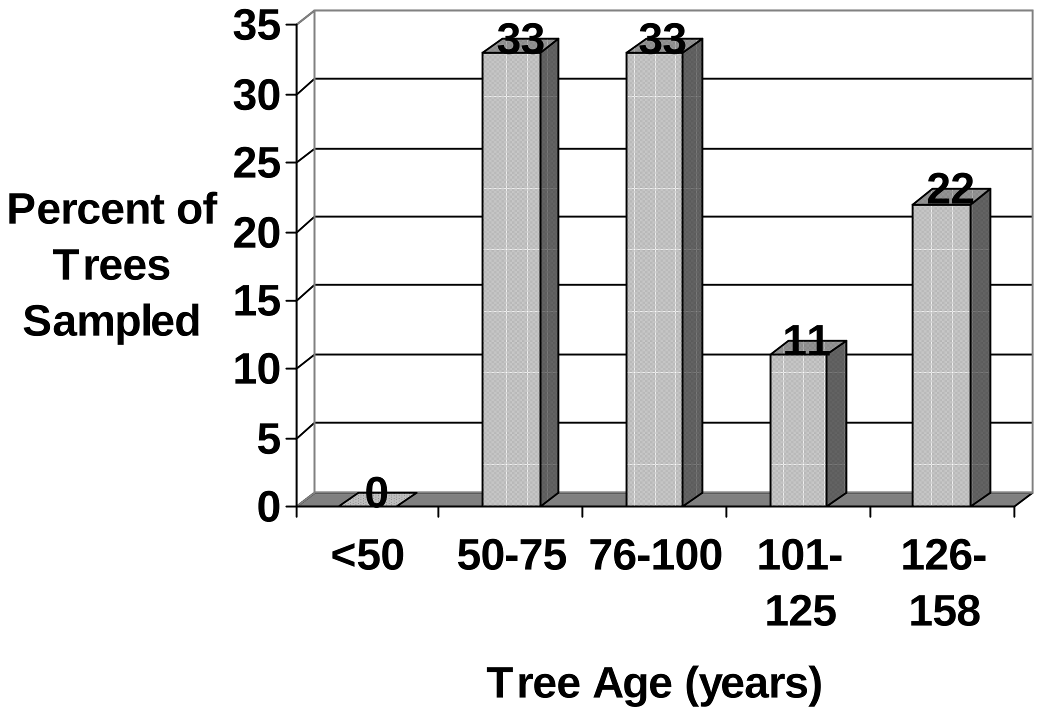


Figure 2—Age distribution of Table Mountain pines sampled on two north Georgia sites.

needed to open serotinous cones; and they reduce thick duff layers or expose mineral soil. However, none of the fires observed in these studies were successful for replacing older stands of mixed pines and hardwoods with newly regenerated stands of pines. Low-intensity medium-low intensity fires failed to kill more than a few overstory trees. High intensity fires killed most overstory trees but had few pine seedlings. Medium-high intensity fires provided abundant overstory mortality and pine regeneration. However, fires of all intensities failed to control competition from hardwood and shrub sprouts.

The support studies presented here provide indirect evidence that frequent burning may restore ridgetop pine communities. The dendrochronology study shows that pines in study stands were uneven-aged and had regenerated frequently until the time of fire exclusion. The seed biology study suggests that a viable seed source is present over a wide range of tree ages and in cones that have been on trees for up to 5 years. Studies of seedbed habitat and mycorrhizal populations provide evidence that the severe conditions produced by high-intensity burning are not necessary and may be detrimental to regeneration. Moisture may be limited due to lack of mycorrhizal tips on roots, loss of a mulching effect from the duff, and direct sunlight reaching the forest floor. These conditions may have been common in pre-1950's stands that burned often.

Results presented here suggest that ridgetop pine stands were created by lower-intensity fires than once were thought necessary, and that such fires would aid in community restoration. Low-intensity prescribed fires, which can be used when the lower layers of the forest floor are moist, are less dangerous and present a larger window of opportunity than high-intensity fires.

ACKNOWLEDGMENTS

Funding for the research described here was awarded by the Department of Interior/Department of Agriculture, Forest Service Interagency Joint Fire Science Program.

LITERATURE CITED

Brose, Patrick H.; Tainter, Frank; Waldrop, Thomas A. Regeneration history of Table Mountain/pitch pine stands in two locations in the Southern Appalachians. [This proceedings].

Ellis, Lisa E.; Waldrop, Thomas A.; Tainter, Frank H. Ectomycorrhizae of Table Mountain pine (*Pinus pungens*). [This proceedings].

Gray, Ellen; Rennie, John; Waldrop, Thomas. Patterns of seed production in Table Mountain pine *(Pinus pungens*). [This proceedings].

Neary, D.G.; DeBano, L.F.; Ffolliott P.F. 2000. Fire impacts on forest soils: a comparison to mechanical and chemical site preparation. In: Moser, W. Keith, ed. Proceedings of the twenty-first Tall Timbers fire ecology conference; 1998 April 14–16; Tallahassee, FL. Tall Timbers Research, Inc.: 85–94.

Southern Appalachian Man and the Biosphere (SAMAB). 1996. The Southern Appalachian assessment terrestrial technical report. Rep. 5 of 5. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region.

Van Lear, David H.; Waldrop, Thomas A. 1989. History, use, and effects of fire in the Southern Appalachians. Gen. Tech. Rep. SE–54. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 20 p.

Waldrop, T.A.; Brose, P.H. 1999. A comparison of fire intensity levels for stand replacement of Table Mountain pine (*Pinus pungens* Lamb.). Forest Ecology and Management. 113: 115–166.

Waldrop, Thomas A.; Mohr, Helen H.; Brose, Patrick H.; Baker, Richard B. 1999. Seedbed requirements for regenerating Table Mountain pine with prescribed fire. In: Haywood, James D., ed. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16–18; Gen. Tech. Rep. SRS–30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 369–373.

Welch, N.T.; Waldrop, T.A.; Buckner, E.R. 2000. Response of Southern Appalachian Table Mountain pine (*Pinus pungens*) and pitch pine (*P. rigida*) stands to prescribed burning. Forest Ecology and Management. 136(2000): 185–197.

Williams, C.E. 1998. History and status of Table Mountain pine-pitch pine forests of the Southern Appalachian Mountains (USA). Natural Areas Journal. 18: 81–90.

Williams, C.E.; Johnson, W.C. 1992. Factors affecting recruitment of *Pinus pungens* in the Southern Appalachian Mountains. Canadian Journal of Forest Research. 22: 878–887.

Zobel, D.B. 1969. Factors affecting the distribution of *Pinus pungens*, an Appalachian endemic. Ecological Monographs. 39: 303–333.

GROWTH RESPONSE FROM HERBICIDE, PRESCRIBED FIRE, AND FERTILIZER TREATMENTS IN MIDROTATIONAL LOBLOLLY PINE: FIRST-YEAR RESPONSE

Mary Michelle Barnett, Sandra Rideout, Brian P. Oswald, Kenneth W. Farrish, and Hans M. Williams[1]

Abstract—This study was initiated to determine growth response resulting from the application of prescribed fire and herbicide, with and without fertilization. In southeast Texas, herbicide, prescribed fire and fertilizer treatments were applied in mid-rotational loblolly pine plantations 1.5 years after thinning. Five replications were established at each of two study sites located on similar soils, aspects and slopes. Half of each replication was randomly selected and fertilized. Eight treatment plots were established in each replication with one of each of the four treatments of control, herbicide, fire, and herbicide/fire randomly applied to fertilized plots and one of each of the four treatments randomly applied to non-fertilized plots. Pre-treatment measurements were taken in a 0.04 ha measurement plot nested within each treatment plot. A late season herbicide treatment of Imazapyr and Arsenal was applied in October 1999. Burning was conducted in early spring of 2000 followed by fertilizer applications of diammonium phosphate and urea. Post-treatment measurements were taken in December 2000. Growth response and significant treatment differences are presented in this paper.

INTRODUCTION

Loblolly pine (*Pinus taeda*) plantations often receive little or no treatment between the time of stand establishment and harvest (Nyland 1996). However, studies have shown the benefit of mid-rotation manipulation in terms of increased pine growth rate, improved species composition, and wood quality (Zutter and Miller 1998, Haywood and others 1998, Borders and Bailey 1997, Cain and Yaussy 1984).

Intermediate treatments include release cuttings to improve species composition, the application of prescribed fire to remove competition and reduce crown fire hazard (Nyland 1996), the application of herbicides to remove competition (Haywood and others 1997), and fertilization to improve growth (Young and Giese 1992).

Because loblolly pine is naturally found on low and moist sites, it has evolved with no special adaptation to fire in its early years (Wright and Bailey 1982). Therefore, the use of fire in loblolly pine stands is often limited to site preparation or competition control and fire hazard reduction at mid-rotation. Although loblolly pine is less fire resistant when young, as trees age, bark thickens (Villarrubia and Chambers 1978, Cooper and Altobellis 1969) resulting in a higher tolerance to moderate fires. In addition, sunlight deprived lower limbs will fall, causing the tree crown to be less accessible to damaging flames. Both of these factors increase the tolerance of loblolly pine to moderate fire (Wade and Lunsford 1988).

Herbicides may be used as an intermediate treatment to remove competing woody vegetation, herbaceous vegetation, or both woody and herbaceous vegetation (Borders and Bailey 1997). Mid-rotational loblolly pine benefits from the removal of woody competition that severely limits its diameter growth and its ability to completely occupy a site (Hodges 1990). However, growth response may vary due to site quality, season of treatment, and type and density of competing vegetation (Lauer and Glover 1990, Hodges 1990). Herbicide and prescribed fire are often applied together as a mid-rotational treatment in loblolly pine stands (Borders and Bailey 1997).

Fertilizer may be used to improve pine tree growth in mid-rotational loblolly pine plantations. Studies over the past 20 years have shown increases in tree growth due to the use of fertilization at mid-rotation (Allen and others 1983, Gent and others 1986). Fertilization may also be best used at mid-rotation when the stand has filled most of the growing space and more nutrients are becoming tied up in living and dead plant material (Smith 1986). Fertilization alone may result in a shift toward competing vegetation, causing increases in pine mortality (Borders and Bailey 1997). It is possible that the addition of fertilizer may result in further reductions in the thickness of loblolly's already moderately protective bark (Tiarks and Haywood 1993). Growth response to fertilization may vary from site to site depending on pre-treatment soil conditions such as nutrients, soil type, and water availability (Borders and Bailey 1997). Chemical herbicide control of competing vegetation may be

[1]Graduate Student, Arthur Temple College of Forestry, Stephen F. Austin State University, Nacogdoches, TX; Associate Professors, Arthur Temple College of Forestry, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

combined with fertilization. Mid-rotational loblolly pine growth may be increased when chemical competition control is added to fertilization (Borders and Bailey 1997).

OBJECTIVES

1. Determine the effect on growth in mid-rotational loblolly pine resulting from the application of prescribed fire and herbicide, with and without fertilization.
2. Compare the effect of fire and/or herbicide applications on competition control in mid-rotational loblolly pine plantations, as well as, determine if any fertilization interaction exist between either or both fire and herbicide.

METHODS

Study Area

Site one is known as the Cherokee Ridge site. This site was hand planted on a 1.83 m X 3.05 m spacing in 1985. In July 1998 this site was thinned to a basal area of 13.10 m^2ha^1. Approximately 465 trees per hectare remain. Soils consist of moderately well-drained to well-drained sandy loam or fine sandy loam surface soil. Slopes range from 3 to 15 percent.

The second site is known as the Sweet Union site. This site was machine planted on a 1.83 m X 3.66 m spacing in 1982. In 1998, the site was thinned to a basal area of 22.26 m^2ha^1. Surface soils consist of loamy sand on slopes that range from 3 to 15 percent. Both sites are located on International Paper Company property.

Plot Establishment

The experimental design for this study is a split plot with fertilizer treatment as the whole plot and vegetation control treatments as sub-plots. Five replications were established at each of the two sites. One–half of each replication was randomly selected and treated with fertilizer. In each replication, 8 treatment plots measuring 0.1 ha were randomly established, leaving approximately a 10-meter buffer between each treatment plot. A measurement plot measuring 0.04 ha was nested within each 0.1 ha treatment plot. The four treatments of control, herbicide, fire, and herbicide/fire were randomly located in the eight 0.1 ha treatment plots, with one of each of the four vegetative control treatments conducted for fertilized and one of each of the four vegetative control treatment conducted for the unfertilized area.

Methodology

Before treatment, each tree within the 0.04 ha measurement plots was identified to species and tagged with a numbered metal tag nailed to the tree at DBH. Treatments were applied after the completion of baseline data collection, approximately 1.5 years after thinning. A late season, ground-applied herbicide treatment was applied in October 1999 to remove competing vegetation. This included the herbicide application for the prescribed-fire/herbicide treatment. Imazapyr and Arsenal was applied at the rate of 5.5-6.9 kg per ha. An early spring burn was conducted in March 2000 prior to green-up to remove competing aboveground stems. Fertilizer treatments were applied with a hand spreader following the fire.

At the end of the 2000 growing season, the height of each numbered tree within the 0.04 ha measurement plot was re-measured using a clinometer and the diameter was re-measured using a diameter tape. Parameters evaluated were height and diameter growth of individual trees.

Analysis of variance for a Randomized Complete Block Design was conducted on data to test for treatment differences and Duncan's multiple range test was used to identify significant treatment differences at the significance level of 0.1 for the response variables of height and diameter growth.

Table 1—Mean height growth (m.) and diameter growth (cm.) in Loblolly pine (*Pinus* taeda) for the Sweet Union and Cherokee Ridge study sites in southeast Texas for the four treatments of control, herbicide, fire, and herbicide/fire. Height (m.) and diameter (cm.) growth for fertilized and non-fertilized plots

	Control		Herbicide/Fire Height		Fire		Herbicides	
	Height	Diameter	Height	Diameter	Height	Diameter	Height	Diameter
Sweet Union	0.82*	0.54	0.75	0.61	0.65	0.62	0.71	0.68
Cherokee Ridge	0.78	1.10*	0.82	1.00	0.71	0.91	0.65	1.12*

	Fertilized		Non-Fertilized	
	Height	Diameter	Height	Diameter
Union	0.76 *	0.60	0.69	0.64
Cherokee Ridge	0.70	1.04	0.77	1.02

*Significant treatment effect at p=0.1 level

RESULTS

Analysis of variance indicated significant treatment effects for the treatments of control and herbicide/fire, as well as, a site/fertilizer interaction for height growth. The site/fertilizer interaction occurred on the Sweet Union site, which possessed greater height growth on control plots that received fertilizer (table 1). In addition, height growth seems to have been affected to a lesser degree on herbicide/fire plots which also received fertilizer. However, too much overlap exists between herbicide/fire and other treatments to consider this significant. Analysis of variance also indicated that diameter growth was significant on the Cherokee Ridge site (table 2). While no fertilization interaction occurred on this site, Duncan's Multiple range test revealed that herbicide and control plots produced significant increases in diameter growth. The mean increase in diameter growth at the Cherokee Ridge site was twice as great as the increase at the Sweet Union site (table 2). Analysis of variance conducted on pre-treatment heights and diameters indicated a significant difference between the two sites for both height and diameter (table 2). The Cherokee Ridge site had taller, larger diameter trees before the application of treatments than the Sweet Union site. Analysis of second year data indicated that while Cherokee Ridge still had taller trees, height growth at the Sweet Union site had increased at the same rate and narrowed the difference between the two sites (table 2). The Sweet Union site, however, has not been able to produce the diameter growth found on the Cherokee Ridge site, which still possessed larger diameter trees and exhibited a significant increase in diameter growth. Significant height and diameter growth was recorded on Replication 2 at the Cherokee Ridge site while significant diameter growth was indicated on Replication 1 at the Cherokee Ridge site.

DISCUSSION

The Cherokee Ridge and Sweet Union study sites were impacted by different silvicultural treatments applied prior to this study. Both sites were thinned in 1998. However, the Cherokee Ridge site was left with a basal area of 13.10 m^2ha^1. Trees were row thinned, as well as, removed from within rows. The Sweet Union site was thinned only by row and left with a basal area of 22.26 m^2ha^1.

Because height growth is less sensitive than diameter growth to stocking density, the Sweet Union site may be responding to less crowded conditions by shifting resources toward height rather than diameter growth. Although both of these stands were seventeen-years-old, significant height and diameter differences were present before treatment. Trees at the Sweet Union site possessed less height than those trees at the Cherokee Ridge site. At one year post-treatment, there were no significant differences between the mean height growth at either site. While trees at the Cherokee Ridge site were still taller, height difference between the two sites has decreased. The fact that height increases at the Sweet union site were significant on fertilized control plots suggests that increases in height growth were a combination of fertilizer and thinning effects. More densely stocked conditions forced trees upward for available sunlight. Trees that were already responding to thinning with height growth, gained more benefit from the additional treatment of fertilizer.

In addition to fertilized control plots, height growth at Sweet Union was also significant on herbicide/fire treatments. Because herbicide was applied prior to the application of fire, hardwood and herbaceous competition was very dry resulting in a more intense fire. Why a more intense fire would result in improved height growth can not be explained at this time. However, it could be speculated that height growth response was more a result of the application of fertilizer rather than the application of herbicide or fire. The fact that significant height growth response was indicated on fertilized control plots that received no other treatment supports this speculation. Diameter at the Cherokee Ridge site was significantly greater prior to treatment than diameter at the Sweet Union site. Because diameter is more responsive to decreases in stocking density, the Cherokee Ridge site may still be responding to less dense conditions with increases in diameter. This may explain the increase in diameter associated with the herbicide treatment. Removal of competition within a plot already responding with diameter increases to less dense conditions increased beneficial results. In both cases, the conclusion may be that trees, which were responding well in either height, diameter, or both, experienced even more improved tree growth with additional treatment. It is important to note that significant treatment effects were calculated using mean increases in height and diameter. Therefore, a tree 30-centimeters in diameter and 18 meters tall had no advantage in statistical calculations over smaller diameter trees that had acquired less height except as an indicator of site productivity prior to treatment. Because control plots received no competition control treatments, treatment effects noted at both sites in control plots for both height and diameter increases indicated lingering thinning responses.

Table 2—Mean pre-treatment and post-treatment height (m.) for Loblolly Pine (*Pinus taeda*) and diameter (cm.) for the Sweet Union and Cherokee Ridge study sites in southeast Texas

Site	*Pre-Treatment*		*Post-Treatment*		*Increase*	
	Height	Diameter	Height	Diameter	Height	Diameter
Sweet Union	15.33*	17.50	16.06	18.11	0.73	0.61
Cherokee Ridge	15.71	19.95*	16.41	20.98*	0.70	1.03*

*Significant at p=0.1 level

CONCLUSIONS

It appears that on both sites, trees that were growing well before treatment were growing as well or better after treatment. Study trees at both sites were among healthy well-growing populations, which appear to have maintained growth with little mortality during this study year, in which southeast Texas experienced a significant drought. Subtle difference occurring among treatments in such a population may be difficult to detect with first year data. Even in a year of normal rainfall, a study with results from only one year cannot reliably answer questions about the use of fertilization and its ability to improve tree growth. Nor do one year's results answer long-term questions about improved growth resulting from the use of competition control. In future years, treatments that appeared to have had no significant impact in first year's data may, in fact, become significant.

REFERENCES

Allen, G.G.; M.J. Cousin; J.F. Friedhoff; R.C. Maggio; W.F Miller; J.C. Powell. 1983. Growth enhancement of a juvenile loblolly pine forest by treatment with a controlled release herbicide. International Pest Control. 6: 172-173.

Borders, B.E; R.L. Bailey. 1997. Loblolly pine - pushing the limits of growth. Athens, GA: University of Georgia; CAPPS: Consortium on Accelerated Pine Production Studies; Technical Report CAPPS 1997-1. 9 p.

Cain, M.D.; D.A. Yaussy. 1984. Can hardwoods be eradicated from pine sites? Southern Journal of Applied Forestry. 8(1): 7-14.

Cooper, R.W.; A.T. Altobellis. 1969. Fire kill in young loblolly pines. Fire Control Notes (Washington). 30(4): 14-15.

Gent, J.A.; H.L. Allen; R.G. Campbell; C.G. Wells. 1986. Magnitude, duration, and economic analysis of loblolly pine growth response following bedding and phosphorus fertilization. Southern Journal of Applied Forestry. 10: 124-128.

Haywood, J.D.; A. Martin Jr.; H.A. Pearson; H.E. Grelen. 1998. Seasonal biennial burning and woody plant control influence native vegetation in loblolly pine stands. Asheville, NC: USDA Forest Service. Southern Research Station Technical report SRS-14. 10 p.

Haywood, J.D.; A.E. Tiarks; M. A. Sword. 1997. Fertilization, weed control, and pine litter influence loblolly pine stem productivity and root development. New Forest. Kluwer Academic Publishers, Netherlands. 14:233-249.

Hodges, D.G. 1990. Profitability of hardwood and herbaceous weed control in loblolly pine stands. In: Coleman, S.S.; Neary, D.G., eds. Proceedings of the Sixth biennial southern silvicultural research conference; 1990 October 30 - November 1, Memphis, TN. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 811-821.

Lauer, D.K.; G.R. Glover. 1990. A region-wide study to model loblolly pine growth response to degree and timing of harwood control and herbaceous weed control. In: Coleman, S.S.; Neary, D.G., eds. Proceedings of the Sixth biennial southern silvicultural research conference; 1990 October 30 - November 1, Memphis, TN. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 584-590.

Nyland, R. D. 1996. Silviculture concepts and applications. McGraw-Hill. 90-96, 99-105 p.

Smith, D.M. 1986. The practice of silviculture. Eighth edition New York: John Wiley and Sons. 515 p.

Tiarks, A.E.; J.D. Haywood. 1993. Bark yields of 11-year-old loblolly pine as influenced by competition control and fertilization. In: Brissette, J.C., ed. Proceedings of the Seventh biennial southern silvicultural research conference; 1992 November 17-19, Mobile, AL. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 525-529.

Villarrubia, C.R.; J.L. Chambers. 1978. Fire: Its effect on growth and survival of loblolly pine, *Pinus taeda L*. Louisiana Academy of Science. 41: 85-93.

Wade D.D.; J.D. Lunsford. 1988. A guide for prescribed fire in southern forest. U.S.F.S. Southern Region Tech. Report R8-TP11. Atlanta, GA: United States Department of Agriculture.

Wright H.A.; A.W. Bailey. 1982. Fire Ecology, United States and southern Canada. New York: John Wiley and Sons, Inc. 302 p.

Young R.A.; Ronald L. Giese. 1982. Introduction to forest Science. 2nd ed. New York: John Wiley and Sons, Inc. 304-306 p.

Zutter, B.R.; J.H. Miller. 1998. Eleventh-year response of loblolly pine and competing vegetation to woody and herbaceous plant control on a Georgia Flatwoods site. Southern Journal of Applied Forestry. 22(2): 88-95.

Pine Thinning and Spacing

Moderator:

CLARK BALDWIN
USDA Forest Service

ECONOMIC RATIONALE FOR PLANTING LESS TREES IN THE FACE OF SEEDLING MORTALITY

Thomas J. Dean and S. Joseph Chang[1]

Abstract—Simple economic analyses are used to demonstrate that planting extra trees to compensate for initial seedling mortality can actually reduce the profit expected from a pine plantation. At a 6-percent interest rate, the cost of planting 15 or 25 percent additional seedlings compounded to the end of a 30-year rotation exceeds the revenue lost to these rates of seedling mortality when the initial target density is 700 and 800 seedlings per acre, respectively. At 8 and 10-percent interest rates, the compounded costs of the additional seedlings always exceed the revenue lost to seedling mortality. Comparing the marginal costs and benefits of increments of 50 seedlings indicate that optimal planting density decreases in the face of severe seedling mortality. Seedling mortality represents an inefficiency in a forest production system, and unless establishment efficiency can be improved, planting costs will have to be reduced to maximize profitability.

INTRODUCTION

Planting trees plays an important role in the structural development of a stand and its eventual profitability. Much energy has been expended in conducting spacing trials and economic analyses to determine optimal initial spacing (Bennett 1959, Bowling 1987, Caulfied and others 1992, Land and others 1991, Taylor and Fortson 1991). This initial planting density is typically supplemented to compensate for the number of seedlings that experience has shown to die during the first growing season. This practice can actually undermine the initial planning effort and potential profitability of the rotation.

Planting "extra" trees to compensate for initial seedling mortality undermines the initial planning effort by affecting the initial planting costs and potential revenues at the end of the rotation. Seedling costs should be based on costs per established seedling; planting additional seedlings, regardless of initial mortality, will increase cost. Revenue at the end of rotation is a function of rotation length, site quality, and overall stand density throughout the rotation; additional seedlings change stand density. Studies show that trees grow in relation to proximity and size of neighboring trees (Stiell 1978 and 1982). Consequently, when additional trees are planted, the majority of the plantation is overstocked relative to management objectives. The increased density reduces average diameter growth and the number of trees in the more valuable product classes.

The objective of this paper is to demonstrate that initial planting density should not be changed when only light to moderate seedling mortality is expected and that fewer, not greater, numbers of trees should be planted when severe seedling mortality is expected. These outcomes will be demonstrated for loblolly pine (*Pinus taeda* L.) in the western Gulf region and will be supported by two simple approaches: (1) comparisons of costs and revenues and (2) analysis of marginal costs and marginal benefits of tree planting

METHODS

Seedlings were assumed to cost $0.05 and $0.07 to plant (Dubois and others 1999), and seedling and planting costs were compounded at 6 percent per year to the end of a 30-year rotation. Revenue at the end of the rotation was calculated with the program COMPUTE_MERCHLOB (MERCHLOB for short) (Busby and others 1990). This program projects growth and yield for loblolly pine plantations in the western Gulf area and then calculates the product mix that produces the greatest revenue based on product specifications and prices. Products considered in this demonstration include pulpwood, chip and saw, and sawtimber with unit prices of $26.00/cord, $90.00/cord, and $400.00/MBF, respectively (table 1). Growth projections do not include thinning and were conducted with a site index of 65 feet at a base age of 25 years.

Table 2 presents the results of a simple comparisons between the variable costs of planting compounded to the end of the rotation and revenue loss resulting from mild and moderate seedling mortality rates of 15 and 25 percent, respectively. The compounded costs of planting 15 or 25 percent more seedlings are compared with the projected revenue lost with 15 or 25 percent less seedlings than planted at the beginning of the rotation. Gaps are created in the plantation when seedlings die, resulting in trees growing closer together than the overall number of seedlings would indicate. In this comparison no allowance was made in the growth and revenue projections for the variation in spacing caused by seedling mortality. In other

[1]Associate Professor; Professor, School of Forestry, Wildlife, and Fisheries, Louisiana State University Agricultural Center, Baton Rouge, LA 70803, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

words, spacing between surviving seedlings was considered uniform for all projections. This probably underestimates the growth lost to seedling mortality because average stand diameter would be larger with uniform spacing and thus, more valuable than trees in a stand with the same number of trees but with closer, overall spacing.

Marginal analysis is used to demonstrate the effect of seedling mortality on optimal planting density. Marginal analysis is based on the law of diminishing marginal returns and compares the additional cost of each increment step of input with the resulting incremental change in benefit. The optimum input level occurs when the incremental or marginal cost equals the marginal benefit. Dean and Chang (in press) detail the procedure for using marginal analysis to determine optimum planting density. For this analysis, marginal cost is the cost of additional established seedling lots of 50 compounded at 6 percent for 30 years, and marginal benefit is the change in revenue associated with each increase of 50 additional established seedlings. Seedling mortality transfers their cost to the surviving seedlings; therefore, the cost of seedling mortality is represented in this analysis by increasing the per seedling costs by either 15 or 25 percent. Revenues are calculated with MERCHLOB for rotations of 30 years with no thinning on sites with a site index of 65 ft at a base age of 25 years.

RESULTS

At a 6 percent annual interest rate, the cost of planting additional seedlings compounded to the end of the rotation is less than the projected revenue loss due to seedling mortality for planting densities less than 800 seedlings per acre (table 2). When the target planting density is 800 seedlings per acre, the expected revenues lost with mild and moderate seedling mortality rates are $30.20 and $97.53 per acre, respectively. The costs of planting 15 and 25 percent more than the target number of 800 seedlings per acre compounded at 6 percent to the end of the rotation exceed the respective revenue losses from seedling mortality by $57.40 and $48.47 per acre. At 8 and 10 percent interest rates, the costs for compensating for initial seedling mortality always exceed the expected revenue losses for the target planting densities investigated in this demonstration (table 2).

Marginal analysis of the costs and benefit of each 50 seedling increase in surviving density indicates that with

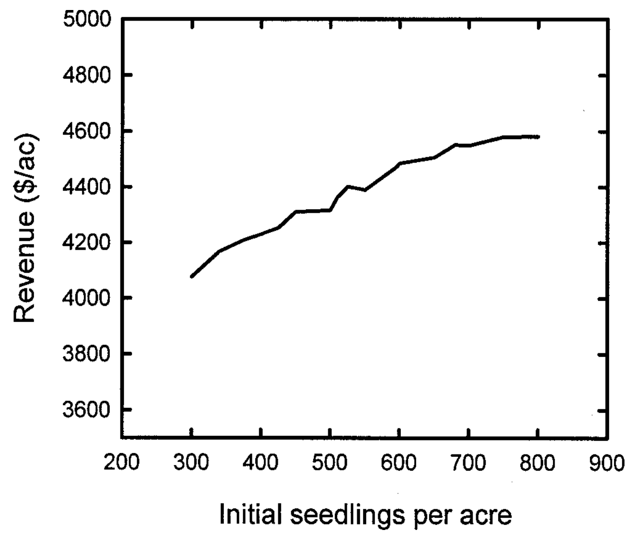


Figure 1—Revenue at the end of a 30-year rotation as projected by the growth-and-revenue simulator COMPUTE_MERCHLOB as a function of initial seedlings per acre for loblolly pine plantations with no thinning.

100 percent seedling survival and a 6 percent interest rate, the optimal number of established seedlings is 700 per acre because the additional revenue gained from having 750 surviving seedlings per acre over having 700 surviving seedlings per acre is $15.37/acre less than the cost of the additional seedlings (table 3). Marginal seedling costs increase $5.40/acre with mild initial seedling mortality, but the increase is not enough to affect the optimum planting density. The increased seedling cost of $9.07 associated with moderate seedling mortality is enough to affect optimum planting density. When 25 percent of the seedlings are expected to die, the marginal cost of each 50-seedling increase in surviving density is $45.37/acre which is greater than marginal benefit of each successive 50-seedling increase in surviving density greater than 600 seedlings per acre.

DISCUSSION AND CONCLUSION

According to MERCHLOB, projected revenue at the end of a 30-year rotation steadily (though not monotonically) increases as initial planting density increases from 300 to 800 seedlings per acre (figure 1). At the lower part of this range, planting additional seedlings to compensate for initial mortality actually increases revenue at a faster rate

Table 1—Product specifications and prices used in COMPUTE_MERCHLOB to calculate revenues (Dubois and others 1999)

Product Category	Price per unit	Minimum diameter	Maximum diameter
	$	*inches*	*inches*
Pulp wood	26.00/cord	3.5	12.0
Chip-and-saw	90.00/cord	6.0	12.0
Saw timber	400.00/MBF[a]	9.5	18.0

[a]MBF = 1,000 board feet Doyle scale

Table 2—Projected revenue lost in a loblolly plantation across a range of initial seedlings per acre (SPA) due to two rates of seedling mortality compared with the cost of planting additional seedlings to compensate for the mortality rate compounded for a 30-year rotation with various annual interest rates. Values are dollars per acre, and revenue projected with the growth-and-revenue generator COMPUTE_MERCHLOB.

	Seedling mortality rate							
	15 pct				25 pct			
	Revenue loss	Cost of additional seedlings			Revenue loss	Cost of additional seedlings		
SPA		6 pct	8 pct	10 pct		6 pct	8 pct	10 pct
	$/ac							
400	61.93	43.80	102.00	144.60	153.88	73.00	170.00	241.00
500	62.42	54.75	127.50	180.75	107.88	91.25	212.50	301.25
600	121.84	65.70	153.00	216.90	173.62	109.50	255.00	361.50
700	77.33	76.55	178.50	253.05	146.77	127.75	297.50	421.75
800	30.20	87.60	204.00	289.20	97.53	146.00	340.00	482.00

than costs escalate with a 6 percent interest rate. At the upper end of this range (and at the uppermost of the range for the moderate mortality rate), however, the associated costs of additional seedlings equal or exceed the additional revenue gained with the extra seedlings; the best outcome with a 6 percent interest rate is a wash. With 8 and 10 percent interest rates, the additional seedlings always cost more than the recovered revenue.

The simple comparisons of the cost of planting additional seedlings and the revenue that the additional is intended to recover at the end of the rotation is actually a form of marginal analysis. The main difference is that the simple comparisons are evaluating revenue recovered with the cost of compensating for seedling mortality, whereas, with comparison marginal analysis, the cost of an additional surviving seedling is compared with the additional revenue it produces. Since the costs of seedlings that die are assigned to the surviving seedlings, seedling mortality acts to increase marginal planting costs, which for moderate and worse mortality rates, results in lower planting densities. Increasing interest rates also result in lower planting densities that optimize profit.

Table 3—Marginal analysis of costs and benefits for planting additional seedling lots of 50 loblolly pine seedlings per acres (SPA). All values are dollars per acre. Revenue projected with COMPUTE_MERCHLOB with no thinning. Marginal costs calculated with an interest rate of 6 percent. Optimal planting density for each mortality rate designated with a (*).

SPA	Revenue	Marginal benefit	Marginal costs		
			0 pct mortality	15 pct mortality	25 pct mortality
	$/ac				
550	4390.06				
		95.19	36.30	41.70	45.37 (*)
600	4485.25				
		20.93	36.30	41.70	45.37
650	4506.18				
		42.94	36.30 (*)	41.70 (*)	45.37
700	4549.02				
		31.60	36.30	41.70	45.37
750	4580.62				
		2.16	36.30	41.70	45.37
800	4582.78				

Seedling mortality can be treated as a measure of inefficiency, and inefficiencies always increase costs relative to revenues, especially in an enterprise that requires decades to produce its product. This analysis demonstrates that in many cases, attempting to overcome establishment inefficiency with increased numbers of seedlings will reduce profitability. Until the establishment efficiency can be improved, input or planting costs need to be reduced to maximize profitability. Focusing on establishment efficiency, i.e., seedling survival, will probably be more beneficial to the enterprise than overplanting to compensate for seedling mortality. Many factors are known to increase initial seedling survival. These factors include prudent site preparation, correctly matching species with site, and following the recommended procedures for storing, transporting, handling, and planting seedlings. According to these analyses, the most profitable operation will be obtained by following the establishment prescription and maximizing establishment efficiency by properly executing each element of the plan.

REFERENCES

Bennett, F.A.; McGee, C.E.; Clutter, J.L. 1959. Yield of old-field slash pine plantations. Paper No. 107. Asheville: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experimental Station. 19 p.

Bowling, D. 1987. Twenty-year slash pine spacing study: what to optimize. In: Phillips, Douglas R., ed. Proceedings of the Fourth Biennial Southern Silviculture Research Conference; 1986 November 4-6; Atlanta. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 300-304.

Busby, R.L.; Ward, K.B; Baldwin, Jr, V.C. 1990. COMPUTE_MERCHLOB: a growth and yield prediction system with a merchandising optimizer for planted loblolly pine in the West Gulf region. Research Paper SO-255. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 22 p.

Caulfied, J.P.; South, D.B.; Somers, G.L. 1992. The price-size curve and planting density decisions. Southern Journal of Applied Forestry. 16(1): 24-29.

Dean, T.J.; S.J. Chang. in press. Using simple marginal analysis and density management diagrams for prescribing density management. Southern Journal of Applied Forestry.

Dubois, M. R.; McNabb, K.; Straka, T.J. 1999. Costs and cost trends for forestry practices in the South. Forest Landowners. 58: 3-8.

Land, S. B. Jr.; Belli, K. L.; Duzan, H. W. Jr. 1991. Family, spacing, and family-by-spacing effects on loblolly pine during five years after planting. In: Coleman, Sandra S. and Neary, Daniel G., eds. Proceedings of the Sixth Biennial Southern Silviculture Research Conference; 1990 October 30-November 1; Memphis. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 744-756.

Stiell, W. M. 1978. How uniformity of tree distribution affects stand growth. The Forestry Chronicle 54: 156-158.

Stiell, W. M. 1982. Growth of clumped vs. equally spaced trees. The Forestry Chronicle 58: 23-25.

Taylor, R.G.; Fortson, J.C. 1991. Optimum plantation planting density and rotation age based on financial risk and return. Forest Science. 37(3): 886-902.

LOBLOLLY PRUNING AND GROWTH CHARACTERISTICS AT DIFFERENT PLANTING SPACINGS

J.C. Adams and T.R. Clason[1]

Abstract—In 1990, an abandoned farm pasture located on the Calhoun Research Station, Calhoun, Louisiana was planted in loblolly pine (*Pinus taeda L.*) at five different spacings. The spacings were 12X6, 12X8, 10X6, 16X6 and 24X6. Variables measured were DBH, height, branch diameter, height to first branch and first branch whorl, fusiform occurrence, and forking. Ice damage after an initial thinning was evaluated. The wider spacings generally produced trees with the largest limbs and the shortest height to retained limbs. The higher density stands produced slightly taller but smaller DBH trees. Fusiform and forking were significant but not related to the spacing density. The two highest density stands (10X6 and 12X6) were greatly affected after thinning by the ice storm in 2001. Overall the 12X8 spacing was the best for growth, pruning and had minimal damage when exposed to ice.

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is a fast growing conifer species with the ability to self-prune when growing in stands that have sufficiently dense competition. In stands that have lower planting densities the tendency is to retain limbs longer and produce larger limbs which leads to larger knot size and the production of lower lumber and plywood grades. The densities that produce the most desirable boles (knot free or small knots) do not optimize diameter growth and rapid production of high value saw and plywood logs. There is a fine line between planting density, natural pruning, sustained rapid growth, and yield of economically useable wood. An ideal spacing is one that profitably grows the smallest size usable tree (Smith and others 1997).

The question is, what is the optimum planting density that will maintain consistent growth rates and stimulate natural pruning, decreasing the number and size of limbs, and increasing the height to retained limbs? Also, initial spacing affects bole strength during early plantation development (Wiley and Zeibe 1991; Amateis and Burkhart 1996; Belanger and others 1996). Trees planted at wider initial spacings have slightly more taper are less likely to suffer the effect of strong winds and ice damage problems when thinned. The key to productive loblolly pine plantations is to maintain an acceptable growth rate and develop a strong central bole with enough intraspecific competition to facilitate natural pruning.

There is limited information on the development and loss of limbs at various spacings and the growth of the stands in diameter, height, and bole strength. A loblolly pine plantation planted at various spacings in north central Louisiana was used to evaluate the effect of various levels of competition on branching characteristics and tree growth.

METHODS

In February 1990, a loblolly pine plantation was established on the Calhoun Research Station, Louisiana Agricultural Experiment Station, Calhoun, Louisiana. The area had been part of a pasture and cattle management research program for several decades and was covered with bahiagrass, bermudagrass, and other forages. The soils are composed of approximately 50/50 Ora-Savannah and Ruston-Lucy associations. The Ora is a fine loamy, siliceous, semi active, thermic Typic Fragiudult, and the Savannah is a fine-loamy, siliceous, semi active, thermic Typic Fragiudult. The Ruston is a fine-loamy, siliceous, semi active, thermic Typic Paleudult, and the Lucy is a loamy, kaolinitic, thermic Arenic Kandiudult. These pastures had been limed and fertilized for forage production.

The site was originally planted to investigate straw production for the landscaping industry and the impact that the repeated removal of straw would have on the long-term site productivity. Five different planting densities were used to facilitate and evaluate the removal of the pine straw and the application of chicken litter as a fertilizer. They included 10X6, 12X6, 16X6, 24X6, and 12X8 foot spacing arrangements having initial seedling densities of 726, 605, 454, 302, and 454 seedlings/acre. These planting densities were duplicated over the 50-acre site. Planting stocks were

[1]Professor, School of Forestry, Louisiana Tech University, Ruston, Louisiana 71272; Professor, Louisiana State University Agricultural Center, Hill Farm Research Station, Homer, Louisiana 71040.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

commercially available, genetically improved seedlings and were machine planted. Herbaceous weed control in the row was done with a herbicide tank mixture of oust/velpar.

In 1999, the stand was measured for natural pruning and growth characteristics. No fertilizer had been applied or straw removed prior to the initiation of the measurements. Four one-tenth acre plots were randomly selected and measured in each of the spacings. Measurements taken were height to the first limb stub, height to the first live limb, height to the first branch whorl, diameter of whorl limbs, DBH, total height, height to first fork, and occurrence of fusiform rust. The design was a completely randomized with five treatments. Analysis of variance was done to determine significance and Duncan's Multiple Range Test was conducted for means separation (SAS 1995).

RESULTS AND DISCUSSION

Limb Height Characteristics

The height from the ground to the first non-pruned dead limb was significant ($P > 0.05$)(table 1). The 10X6 had the greatest height (1.36 ft.) to the first dead branch and the 12X8 had the least (1.15 ft.). However, the difference between the largest and smallest mean was only 0.21 inches, which has little impact on stand development.

The height to the first live limb and first whorl were both significant ($P<0.05$). The emerging pattern was expected, and natural pruning was less on wider spaced (table 1). The height to the first live limb was greatest in the 12X6 (12.1 ft.) and the least was in the 24X6 (7.3 ft.). The height to the first whorl was similar with the 10X6 having the greatest height (14.8) and the 24X6 having the least height (9.9).

Branch and Stem Diameter

The size of the live branches was related to planting density, wider the spacing the greater the branch diameter (table 1). Branch diameter was significant ($P<0.05$) with a range from 0.70 for the 10X6 spacing to 0.94 for the 24X6 spacing, a considerable size difference for nine-year-old trees.

Total Height and DBH

Mean total height among planting densities differed significantly ($P<0.05$) (table 2). The widest spacing, 24X6, had the shortest trees (27 feet), which can be attributed to the lack of competition causing wide crown architecture and short trees. The 12X8 had the tallest trees with a mean height of 36 feet. The other three spacings were intermediate. These trees are only nine years old and, with the exception of the widest spacing, the spacings are becoming less variable over time and will probably reach an equality in height in a few years. This would follow the pattern described by Barnes and others (1998) on the use of height as an indicator of site and the use of height as the major component in site index determinations.

DBH differed significantly among planting densities ($P<0.05$)(table 2). Mean DBH on the 12X8 spacing exceeded all other planting densities with the 10X6 and 12X6 having the smaller DBH. Since diameter is sensitive to intraspecific competition, this was expected. However, DBH on the widest spacing (24X6) ranked third among treatments and was significantly smaller than the 16X6 DBH. The unusual competition pattern with competition rectangles of 6 feet on one side and 24 feet on the other may have influenced tree growth on the 24x6 spacing.

Fusiform, Forking and Ice Damage

Fusiform and forking were present in the stand with approximately 22 percent of the stems damaged by fusiform and approximately 20 percent having a fork. Although there were significant differences between the spacings for the occurrence of fusiform and forking, there appeared to be no pattern between fusiform and spacing and between forking and spacing. The initial hypothesis was that the density of spacing might affect the movement of the fusiform spores and thus cause differing infection rates. The 12x6 and 16x6 spacings had the highest infection rate while the 10x6 spacing had one of lower infestation rates and the 24X6 spacing had the lowest infection rate (table 2). Thus the hypothesis was rejected and there is no pattern in this stand for fusiform infestation. Forking appeared to be uniform among the spacings except for the 12X6, which had a significantly lower forking rate. However, this appears to be chance and no pattern was detectable.

Table 1—Height to limbs and diameter of live limbs in stands with different spacing densities

Spacing	Height First Live Limb	Height First Live Whorl	Height Diameter of	Diameter First Live limb
	---------------------------------Feet	-----------------------------------		Inches
12X8	1.15^{b}	10.8^{b}	13.1^{bc}	0.82^{bc}
12X6	1.22^{b}	12.1^{a}	13.4^{b}	0.76^{c}
10X6	1.36^{a}	11.9^{a}	14.8^{a}	0.70^{d}
16X6	1.35^{a}	9.6^{b}	12.9^{c}	0.86^{b}
24X6	1.16^{b}	7.3^{b}	9.9^{d}	0.94^{a}

Means followed by the same letter are not significantly different at the $P<0.05$ probability level.

Table 2—DBH, total height, fusiform, and forking occurrence and ice damage in stands of different spacing densities

Spacing	DBH	Height	Fusiform	Forking	Unsalvageable
	inches	feet	-------------------	Percent	-------------------
12x8	7.2[a]	36[a]	20	23	5
12x6	6.3[c]	32[c]	29	11	25
10x6	5.8[d]	34[b]	18	27	41
16x6	7.0[ab]	32[c]	29	20	7
24x6	6.7[b]	27[d]	14	20	2

Means followed by the same letter are not significantly different at the $P < 0.05$ probability level.

After the measurements were completed the stand was row thinned with individual selection within the rows (summer 2000) to bring standing density to 200 trees/acre or to a basal area of 50 to 60 feet^2/acre. In December 2000, two consecutive ice storms occurred in the thinned stands. The results were very dramatic. Trees in the two higher planting densities (10X6 and 12X6) were damaged significantly, 41 and 25 percent of the respective stems non-salvageable because of breakage of the main bole or extreme, non-recoverable bending of the main stem. Non-salvageable stems on the other three densities average five percent or less. Wider spaced trees had significantly larger diameters and apparently stronger central stems than the trees planted at the closer spacings. This resulted in the considerably less ice damage in the wider spaced stands, and these stands will continue to grow and produce whereas the high-density stands will have to be replaced.

CONCLUSIONS

Although these stands were originally designed for access in needle collection and poultry litter application, the different initial spacings and their growth provide some insight into the development of the various density stands. Generally, trees planted at wider spacings had shorter retained limb distance, larger limb diameter and larger tree diameters. The widest spacing (24x6) reduced height growth; trees had wider, shorter crowns and were generally rough in appearance. The two denser stockings (10X6 and 12X6) received severe damage in an ice storm, which suggests the central stems were weaker than trees in the wider spaced treatments. Overall the 12X8 spacing with 454 initial seedlings per acre had the best combination of traits measured. Trees in the 12X8 spacings had better growth, form, natural pruning and were more resistant to ice damage**.** This study does not support the common view that large numbers of trees (700-800) are required and necessary to adequately regenerate stands. It does support the concept of ensuring that strong trees make continuous fast growth with enough competition to enhance form but not cause weakened stand.

REFERENCES

Amateis, R. L.; H. E. Burkhart. 1996. Impact of heavy glaze in a loblolly pine spacing trial. Southern Journal of Applied Forestry. 20(3): 151-155.

Barns, B. V.; D. R. Zak; S. R. Denton; S. H. Spurr. 1998. Forest Ecology. New York: John Wiley and Sons, Inc. 774 p.

Belanger, R.P.; J. F. Godbee; R. L. Anderson; J. T. Paul. 1996. Ice damage in thinned and unthinned loblolly pine plantations infected with fusiforn rust. Southern Journal of Applied Forestry. 20(3): 136-140.

Smith, D. M.; B. C. Larson; M. J. Kelty; P. M. S. Ashton. 1997. The Practice of Silviculture: Applied Forest Ecology. New York: John Wiley and Sons, Inc. 537 p.

Wiley, S.; KB. Zeide. 1992. Development of a loblolly pine plantation. Arkansas Agricultural Experiment Station Report Series. 322 p.

DIAMETER GROWTH OF A SLASH PINE SPACING STUDY FIVE YEARS AFTER BEING THINNED TO A CONSTANT STAND DENSITY INDEX

Jamie C. Schexnayder, Thomas J. Dean, and V. Clark Baldwin, Jr.[1]

Abstract—In 1994, a 17-year old, slash pine (*Pinus elliottii* var. *elliottii*) spacing study was thinned to evaluate the influence of prethinning stand conditions on diameter growth after thinning. Diameter growth and crown dimensions measured just prior to thinning showed that diameter growth was positively related to both initial spacing and average crown dimensions. After thinning, these relationships almost immediately disappeared. The first year after thinning, diameter growth was significantly affected by only the initial 8 x 8-foot spacing treatment and was unrelated to prethinning crown dimensions. From the second to the fifth year after thinning, neither initial spacing nor prethinning canopy dimensions significantly influenced diameter growth. Within the fourth and fifth years after thinning, diameter growth appeared to become inversely related to prethinning crown dimensions, but the pattern was not statistically significant.

INTRODUCTION

Stand density is a major factor that a forester can manipulate in developing a stand. Foresters attempt to maintain stand density in a range that fully utilizes the site for maximum production of desirable, usable volume. By controlling stand density, silviculturists are able to influence species establishment, modify stem quality, rate of diameter growth, and volume production during stand development (Daniel and others 1979). In plantations, density is controlled through initial spacing of seedlings and with thinning. Silviculturists must make a compromise between individual tree growth and total stand growth when choosing appropriate planting spacing. At relatively close initial spacings, stand yields are usually highest, whereas individual tree growth is normally best at relatively wide spacings (Long 1985). Thinning is an important silvicultural practice for improving tree growth by redistributing growth and increasing the growth rates of residual trees. It also allows forest managers to select trees to which additional growth will be allocated.

Many stand density measures are considered expressions of the average area occupied or average area available per tree relative to some standard condition (Curtis 1970). Reineke's stand density index (SDI) (Reineke 1933) expresses stand density in terms of the equivalent number of trees in a stand at a standard diameter of 10 inches (SDI = TPA $(QMD/10)^{1.6}$ where TPA = number of trees per acre and QMD = quadratic mean diameter (inches) at breast height). Advantages of using SDI as a measure of stand density are that it is independent of site, age, and species and is easily calculated.

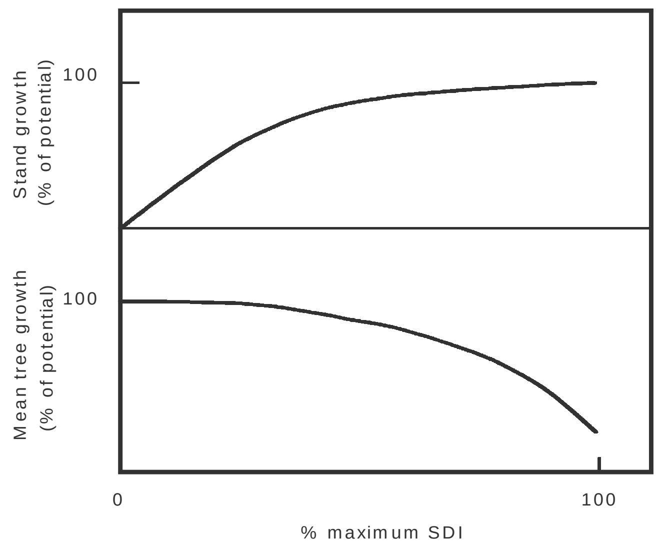


Figure 1—Hypothetical relationship between current annual growth and level of growing stock

Long (1985) illustrated the general relationship between current annual stand and individual tree growth as related to growing stock (figure 1). Relative SDI expresses growing stock relative to the species maximum SDI. The maximum SDI for slash pine is 450 (Dean and Jokela 1992). Since both stand and tree growths are functions of growing stock, stands of the same age and growing on the same site should have equal growth rates. When thinning is involved, however, potential tree growth is probably more strongly related to stand density prior to thinning for some time after thinning.

[1]Graduate Research Assistant and Associate Professor, respectively, School of Forestry, Wildlife and Fisheries, Louisiana Agricultural Experiment Station, Louisiana State University Agricultural Center, Baton Rouge, LA; Section Head, Information Management, USDA Forest Service, Asheville, NC, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

The overall purpose of this research is to analyze the magnitude and the duration of the effects of prethinning stand conditions on diameter growth after thinning. With the expectation that plots thinned to a common SDI should exhibit the same growth rate, any differences in growth should be due to stand conditions prior to thinning.

METHODS

The study area is located about 1 mile east of Woodworth, LA, on the Alexander State Forest, which is managed by the Louisiana Office of Forestry. The soil is a Kolin silt loam with a clayey lower subsoil that restricts internal drainage. However, a slight slope in topography allows adequate surface runoff. This study was installed in the winter of 1976-1977 with planting stock from a single seed orchard of genetically improved parents. Seven spacing treatments (4 x 4, 4 x 6, 6 x 6, 6 x 8, 8 x 8, 10 x 10, and 14 x 14 feet) were randomly assigned to plots within five blocks. Each measurement plot consisted of 8 rows of 8 trees. A one-half chain (33 feet) isolation strip surrounded each measurement plot with trees of the same spacing.

At age 17, all plots within three of the blocks were thinned to 35 percent of the maximum SDI. Three of the spacing treatments were not included in this study. An ice storm shortly after thinning eliminated the 4 x 4 and 4 x 6 spacings from the study, and the 14 x 14 spacing was not used because the average stand density was too low for it to be thinned when the thinning treatments were applied. Additional information about the plots and the original study can be found in Ferguson and Baldwin (1995) and Baldwin and others (1995).

Trees were measured at age 15 years and before and after thinning at age 17 years. The trees were measured annually after thinning until age 22 years for five growth intervals after thinning. Field measurements consisted of diameter at breast height, height to live crown, total height, crown width in two directions at right angles, and crown class was also noted.

Diameter growth was analyzed for each age with a randomized complete block design. Correlation analyses were used to analyze the effect of initial spacing and prethinning crown dimensions on diameter growth after thinning using the simple correlation coefficient. Prethinning crown dimensions consisted of crown width (C_{W0}), crown length (C_{L0}), and crown ratio (C_{R0}). Crown width represents the span of the crown of a tree. Crown length represents the average length of the individual live crown. Crown ratio is the average ratio of crown length and total tree height per plot and is important in maintaining diameter growth and is related to stand density. All significant differences were tested at the 10percent significance level.

RESULTS

Average stand diameter growth of the trees for the different spacings at each age were compared (figure 2). Prior to thinning, diameter growth was strongly and negatively related to stand density. Initial spacing ceased to have any systematic effect on diameter growth the first year after thinning. While initial spacing significantly affected diameter growth one year after thinning, the effect was due to the diameter growth in the 8 x 8-foot spacing. There was no significant difference in diameter growth between the 6 x 6, 6 x 8, and the 10 x 10-foot spacings the first year after thinning (figure 2). The influence of initial spacing on diameter growth diminished each year after thinning as evidenced by the increasing probability of a greater F value from age 19 to 22 years.

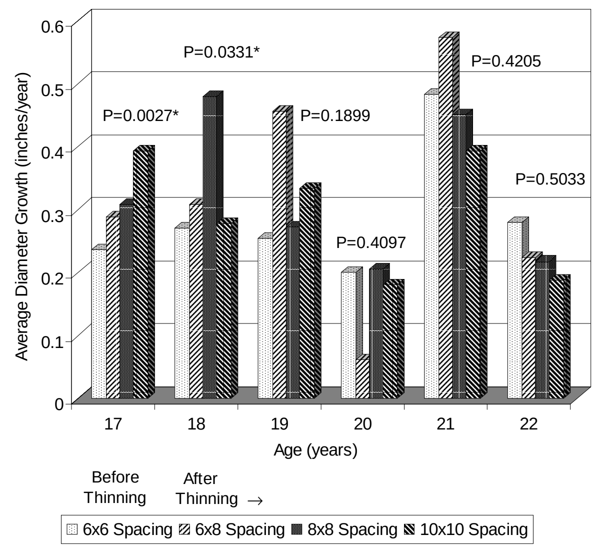


Figure 2—Average diameter growth for each spacing at age 17 before thinning and ages 18-22 after thinning for slash pine near Woodworth, LA

In addition to initial spacing, diameter growth before thinning was strongly related with crown size. Simple correlation coefficients between diameter growth and crown width, crown length, and crown ratio ranged from 0.81 to 0.86 (table 1). One year after thinning and thereafter, however, no correlation existed between diameter growth and crown size prior to thinning. Between the ages of 18 and 20 years, the simple correlation coefficients did not exceed 0.12 (table 1). Four and 5 years after thinning, the correlation

Table 1—Correlation coefficients relating initial spacing and prethinning crown width, crown length, and crown ratio to average mean diameter growth at age 17 (before thinning) and ages 18-22 (after thinning) for slash pine near Woodworth, LA

Correlation Coefficients (r)						
Age	17	18	19	20	21	22 p
C_{W0}	0.81	0.12	0.05	0.07	-0.37	-0.35
C_{L0}	0.86	0.01	-0.02	0.11	-0.33	-0.26
C_{R0}	0.84	0.12	0.06	0.07	-0.36	-0.39

coefficient became increasingly negative suggesting that diameter growth was becoming inversely related to initial spacing; however, the coefficients were not statistically significant (P > 0.20).

DISCUSSION

In general, results support the hypothesis that diameter growth is a function of growing stock and that stands thinned to a common level of stand density will have equal rates of diameter growth. Prior to thinning, average diameter growth was highest for the lowest stand density and decreased systematically with increasing density (figure 2). This trend is supported by the correlations between diameter growth and crown size for age 17 (table 1). The strong correlation between diameter growth, initial spacing, and crown size prior to thinning agrees with previous results (e.g., Curtin 1964, Smith and Bailey 1964, Hamilton 1969).

The effect of stand density on stem growth is generally considered to be through the effect of density on crown size. Since conifer crowns grow in size from the terminal buds, diameter growth was expected to be related to prethinning crown size for some time after thinning. However, the first year after thinning, the correlation between diameter growth and crown size that existed prior to thinning disappeared (table 1), and with the exception of the trees in the 8 x 8-foot spacing, initial spacing did not significantly influence diameter growth (figure 2).

Strub and Bredenkamp (1985) found that plots of loblolly pine (*Pinus taeda*) thinned late produced more total basal area than plots thinned early. Growth efficiency is generally inversely related to crown size (Jack and Long 1992), which together with the improved resource availability to the trees after thinning could be responsible for the rapid independence of diameter growth with initial spacing or prethinning crown dimensions. However, the absence of an initial spacing effect or relation to prethinning crown dimensions was not due to accelerated diameter growth in the more narrowly spaced plots; it was due to reduced diameter growth in the 10 x 10-foot spacing the first year after thinning followed by the trees in the 8 x 8-foot spacing the second year. If the combination of growth efficiency and greater resource availability results in more rapid diameter growth of the narrower initial spacings over that of the wider initial spacings, four years were required by these slash pine trees to manifest the effect. While not statistically significant, diameter growth four and five years after thinning generally decreased with increasing initial spacing (figure 2) and increasing prethinning crown size (table 1).

CONCLUSIONS

In general, the study shows that for these slash pine plantations (1) initial spacing significantly affected diameter growth prior to thinning but had little or no effect on diameter growth after thinning; and (2) the strong correlations between crown dimensions and diameter growth that existed prior to thinning disappeared when stands were thinned to a common stand density. These results suggest that prethinning stand conditions may eventually affect diameter growth, but for the first five years after thinning, the data are inconclusive.

ACKNOWLEDGMENTS

The authors would like to thank Donald P. Feduccia for establishing the original spacing study; Robert B. Ferguson, Otto NesSmith, Larry Gillespie, Jim Scarborough, Dennis Tucker, and Albert LeFort, for maintaining and remeasuring the stands studied in this paper; and the Office of Forestry of the Louisiana Department of Agriculture and Forestry for its cooperation in this study.

REFERENCES

Baldwin, V.C.; Dean, T.J.; Ferguson, R.B. 1995. A comparison of density indices in controlling growing stock in a slash pine spacing-thinning study.In: Edwards, M.B., comp. Proceedings of the Eighth biennial southern silvicultural research conference; 1994 November 1-3, Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 461-466.

Curtin, R.A. 1964. Stand density and the relationship of crown width to diameter and height in *Eucalyptus obliqua*. Austrailian Forestry. 28: 91-105.

Curtis, R.O. 1970. Stand density measures: An interpretation. For. Sci. 16: 403-414.

Daniel, T.W.; Helms, J.A.; Baker, F.S. 1979. Principles of Silviculture. New York: McGraw-Hill. 500p.

Dean, T.J.; Jokela, E.J. 1992. A density-management diagram for slash pine plantations in the lower coastal plain. Southern Journal of Applied Forestry. 16(4):178-185.

Ferguson, R.B.; Baldwin, V.C., Jr. 1995. Spacing effects on unthinned slash pine in the West Gulf Region. In: Edwards, M.B., comp. Proceedings of the Eighth biennial southern silvicultural research conference; 1994 November 1-3, Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 473-478

Hamilton, G.J. 1969. The dependence of volume increment of individual trees on dominance, crown dimensions, and competition. Forestry 49: 133-144.

Jack, S.B.; Long, J.N. 1992. Forest production and the organization of foliage within crowns and canopies. Forest Ecology Management. 46: 233-243.

Long, J.N., 1985. A practical approach to density management. Forestry Chronicles. 61: 23-27.

Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. Journal of Agricultural Resources. 46: 627-638.

Smith, J.H.G; Bailey, G.R. 1964. Influence of stocking and stand density on crown widths of Douglas-fir and lodgepole pine. Commonwealth Forestry Review. 43: 243-246.

Strub, M.R.; Bredenkamp, B.V. 1985. Carrying capacity and thinning response of *Pinus taeda* in the CCT experiments. South African Forestry Journal 2: 6-11.

HOW TO DETERMINE WHEN YOUR CONSERVATION RESERVE PROGRAM (CRP) PINE PLANTATION IS READY TO THIN

Andrew J. Londo, Timothy A. Traugott, Stephen G. Dicke, and Scott D. Roberts[1]

Abstract—The CRP program was initiated in 1986 by the United States Department of Agriculture, Farm Services Agency, to protect topsoil from erosion. There have been 308,000 acres of CRP pine plantations established in Mississippi, and 1.2 million acres of CRP plantations have been established nationwide. Many of the CRP pine plantations in Mississippi will soon be ready for the first thinning. Timing and frequency of these first thinnings should be determined by site quality and landowner objectives. However, first thinnings are all too often considered to be a source of income for private landowners, and not a stand improvement tool. While income is a positive result, most landowners in Mississippi want to produce higher value sawlogs rather than low value pulpwood. Timing the first thinning too soon or too late can decrease site productivity and subsequent longer term financial returns for the landowner. The method presented here was developed to assist landowners and foresters in deciding when a first thinning should take place in CRP pine plantations in Mississippi. It is based upon five factors: 1) stand density, 2) natural pruning height, 3), average tree diameter, 4) heights of dominants and codominants, 5) and basal area growth rate. The decision of whether to thin or not is based on these characteristics, rather than on current pulpwood prices. This method provides a sound, unbiased means for foresters and landowners to decide the optimum time for the first thinning of young loblolly pine plantations.

INTRODUCTION

The Conservation Reserve Program (CRP) is the federal government's single largest environmental improvement program (USDA 1997). CRP was established in 1985 to provide participants an annual per acre rent, plus half the cost of establishing a permanent land cover (Dorell et al 1993). To date, approximately 308,000 acres of CRP pine plantations have been established in Mississippi with an average annual rental payment of $45 per acre for 10 years (Londo 2000).

Faculty in the Department of Forestry at Mississippi State University have developed a workshop to teach landowners the proper time to make the first thinning of their CRP pine plantation. This workshop shows them how to measure the following basic forest characteristics: average tree diameter, average tree height, stand density, height to natural pruning, and basal area growth rate. The workshop, as well as the recommended criteria for each measurement will be described.

WORKSHOP MECHANICS

The pine thinning workshops are held in individual counties in conjunction with each County Forestry Association (CFA) and Extension Agent. The first hour of the workshop is held indoors and serves as a lecture period. The lecture is usually given by one of the MSU Area Extension Foresters. The Area Extension Foresters are faculty members in the Department of Forestry and are responsible for conducting Extension forestry programs in their district of the state.

Information concerning pine growth and development, reasons for thinning, and method for thinning pine plantations are discussed. Following this lecture period, the landowners then go to a pine plantation to collect stand data.

With the assistance of forestry faculty and professional foresters, the landowners are broken into groups and disperse through the plantation for measurement collection. All measurements are collected within 100th acre plots. We encourage our participants to collect data on at least ten plots, scattered throughout the plantation. This is the minimum number of plots to get a good representative sample.

A double sampling technique is used to collect data. Plots are distributed systematically in a plantation using compass and pacing. The first sample is a 1/100th acre plot measuring DBH and trees per acre. Within each 1/100th acre plot, a single sample tree in the dominant or codominant crown class nearest plot center is measured for total

[1]Assistant Extension Specialist, Associate Professor, Department of Forestry, Box 9681 Mississippi State,MS 39762; Extension Specialist, 1241 Mound Street, Grenada MS, 38901; Extension Specialist, Central MS Research and Extension Center, 1320 Silver Springs Rd, Raymond MS 39254, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Basal area growth rate by DBH and 3-year radial growth. Bold numbers designate the threshold 10 percent annual rate of growth. Growth rates at or below the threshold indicate it is time to thin

DBH (inches)	3-year wood radial growth (inches)					
	0.3	0.4	0.5	0.6	0.7	0.8
		Basal Area growth rate (% per year)*				
5	**9**	12	15	18	21	25
6	7	**10**	12	15	17	20
7	6	8	**10**	12	15	17
8	5	7	9	11	13	15
9	5	6	8	**10**	11	13

* BA growth (%/year) = [(future BA – current BA) / (3 years * current BA)] * 100%
current BA = [current DBH]^2 * .005454
future BA = [current DBH + (2* radial growth)]^2 * .005454

height, pruning height, and basal area growth. The sample tree selected is also preferably free from any serious defect.

DBH is measured with a diameter tape and total height with a clinometer.

Natural pruning height (height to the first live limb) is measured using an 11 ft pole that is marked into 1-foot increments. Holding this pole, with your arm fully extended, will reach about 18 ft for most people. Lower pruning heights are easily determined by lowering the pole and counting the number of increments lowered. Stem radial growth (used to estimate basal area growth) is measured from an increment core collected at breast height.

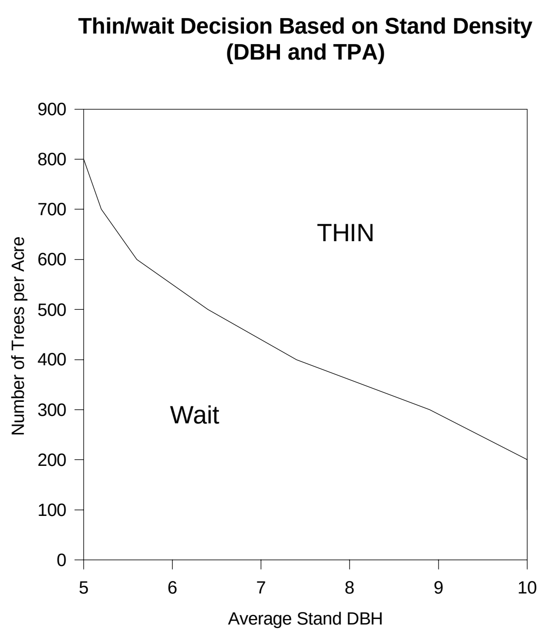


Figure 1—Thin/Wait decision based on 55% Stand Density Index (bold line) for young loblolly pine plantations.

Table 2—Pulpwood tons per tree for pines harvested during the first thinning. From: Jim McCreight. 1998. Unpublished data for Louisiana and Mississippi pine plantations

DBH (inches)	Total Height (feet)*		
	35	40	45
	Tons per tree		
5	0.029	0.030	0.032
6	0.061	0.064	0.068
7	0.095	0.100	0.107
8	0.133	0.140	0.150

* For young pines, merchantable height to a 3" top equals total height minus 10 feet.

A quick field estimate of future basal area growth is provided in table 1 using DBH and radial growth. Radial growth is measured from an increment core of wood taken horizontally through the central pith of the stem of the sample tree at breast height. Width of the growth rings for the last full three years is measured. Predicting future wood growth using past growth is “a reasonable postulate for a 3-5 year span” (Avery and Burkhardt 1994). Bark growth for the three-year period is assumed to be negligible. A simple interest rate was used because a straight-line best describes tree growth in young unthinned stands (Grosenbaugh, 1958). The calculations used to generate table 1 are:

Basal area (BA) is expressed in square feet per tree while DBH and radial growth are in inches.

current BA = [current DBH]^2 * .005454
future BA = [(future BA-Current BA)/(current BA)/(3 years)]*100percent
BA growth rate expressed as percent per year :
BA growth percent = [(future BA – current BA) /(3 years * current BA)] * 100 percent

DBH Measurements

Diameter at Breast Height (DBH) is important, because trees must be at least 5" DBH to be sold for pulpwood (Traugott 2000). Trees smaller than five inches DBH are not merchantable and typically won’t be cut. Consequently, thinning plantations when only the larger trees are above this minimum size may result in high grading of the stand (Traugott 2000). We recommend at least an average tree diameter of six inches. Larger diameter trees also produce more volume, increasing the money earned by the land-owner at the time of thinning.

Other data may also be collected, such as the number of forked, diseased, or ice-damaged trees. Ice storms in 1994 and 1998 have damaged many pine plantations in North Mississippi. This information can be important for determining stand health and allowing for an informed decision on which trees to cut.

Table 3—Summary table for evaluating pine plantation characteristics measured in the field in order to determine whether plantation is ready to be thinned

Characteristic	Guideline	Ready for Thinning?		
Average DBH	$\geq$ 6 inches	YES	Borderline	NO
Trees Per Acre				
Stand Density Index from figure1	$\geq$ 55%	YES	Borderline	NO
Total Tree Height	$\geq$ 40 feet	YES	Borderline	NO
Natural Pruning Ht	$\geq$ 18 feet	YES	Borderline	NO
Basal Area Growth Rate	$\leq$ 10%?	YES	Borderline	NO
What Do We Recommend?	THIN	WAIT __ yrs		

Stand Density

The average tree DBH and number of stems per acre can be used to determine if the stand is dense enough to warrant thinning. Figure 1 shows a “thin – wait” decision line for loblolly pine. This line represents combinations of mean tree diameter and density that equate to 55 percent of the maximum Reineke’s Stand Density Index value (SDI) for loblolly pine (Reineke 1933). Fifty-five percent of maximum SDI is where density-related mortality (self-thinning) can be expected to begin (Dean and Baldwin 1996).

A stand density index value of 55 percent was set as a general target rather than an absolute thinning criteria. Thinning a stand prior to this density may be desirable if a landowner is interested in maintaining high stand vigor and rapid individual tree growth. Delaying thinning beyond this density may be desirable if a landowner is willing to risk some mortality in order to capture a greater total stand volume yield. In addition to stand density index values, the decision of whether to thin or not must also take into consideration the other plantation characteristics discussed in this paper.

Tree Heights

Trees should be at least 40 feet tall for a plantation to be economically thinned (Traugott 2000). We are assuming that the top ten feet needs to be cut off to reach a 3-inch top. Logging operations in Mississippi typically use tree-length log trucks to haul trees from the woods to the mill. Merchantable stem lengths shorter than 30 feet create several problems for the logger. Double stacking short stems results in the truck being full of wood, but typically weighing less than the maximum haul weight of 25 tons (table 2). Higher hauling costs for short trees subsequently lowers stumpage prices for the landowner.

Natural Pruning

Since pines are shade intolerant, their branches die from the ground up as trees become crowded and over topped (Traugott 2000). Natural pruning needs to be at a minimum height of 18 feet. This 18 feet of natural pruning will result in a clear 16-foot butt log for future harvests. This is a much lower standard than the 24 ft reported by Nebeker et al (1986) which would achieve almost 1.5 clear logs.

Natural pruning is most important in the butt log since it is the largest and most valuable log in the tree. Live limbs produce knots in the wood, decreasing strength and subsequent value as lumber. Pruning can be used to achieve the same results, but most landowners do not have the time or money to invest in this kind of operation.

Thinning before natural pruning occurs will allow limbs to live longer and get larger in diameter. What could have been future quality sawtimber is pulpwood or at best low-grade sawtimber. Current prices in Mississippi show this to be a $20 to $30/ton loss in value, or $200-$300 per acre.

Basal Area Growth

One important factor that affects the best time to thin is basal area growth of individual trees. Basal area is the stem cross-sectional area at breast height. Slow growth in basal area is an indicator of poor tree health and increased risk of loss to southern pine beetles. Basal area growth is also an important financial measurement because it is closely related to volume growth (Wenger 1984).

A general target of 10 percent basal area growth is useful for field evaluations. The choice of an acceptable growth rate is a personal one. Landowners reinvesting thinning income at a rate of return above 10 percent will thin earlier. If low rates of return 5 percent or less are expected from reinvestments, landowners will thin later. In general, trees growing over 10 percent each year are producing enough wood to justify waiting to thin. Once basal area growth drops to 10 percent or less there is financial incentive to thin.

Evaluation of Data

At the end of the workshop, we summarize all the data collected and determine if the pine plantation is ready to thin. The format to summarize and evaluate the data collected during the workshop can be found in table 3. We base the decision of whether to thin the plantation on the five factors listed.

SUMMARY AND CONCLUSIONS

There are thousands of acres of CRP pine plantations in Mississippi that are approaching the time for the first thinning. Proper timing is the most important management decision landowners can make for their pine plantation. The first thinning sets the stage for the future productivity and value of the plantation.

The method presented in this paper for determining the timing of the first thinning in CRP plantations is based on stand diameter, density, total height, natural pruning height, and basal area growth. Threshold levels for each of these factors are provided to indicate the need for thinning. The decision of whether to thin or not is made with specific knowledge of these five stand characteristics, rather than on stand age, appearance, or pulpwood prices. This method is easy to use, straightforward, and can be used by landowners and foresters alike. Modifications for different regions in the south could be easily made based on growth rates and markets in those areas.

ACKNOWLEDGMENTS

This paper has been approved as publication number FO 182 of the Forest and Wildlife Research Center at Mississippi State University.

REFERENCES

Avery, T. E.; Burkhart, H.E. 1994. Forest Measurements 4th Ed. New York, NY: McGraw-Hill, Inc. 408 p.

Dean, T.J.; Baldwin, V.C.; Jr. 1996. Growth in loblolly pine plantations as a function of stand density and canopy properties. Forest Ecology and Management. 82:49-58.

Dorell, T.E.; Straka, T.J.; Moulton R.J.. 1993. An economic analysis of federal forestry cost share allocations 1985-1992. Efficiency of allocation related to forest productivity, economies of scale, and type of forestry practice. P. 561-562. In: Proceedings of the Society of American Foresters, 1993 National Convention: 561-562.

Grosenbaugh, L. R. 1958. Allowable cut as a new function of growth and diagnostic tallies. Journal of Forestry 56: 727-730.

Londo, A.J. 2000. The effects of forest fragmentation on forest management for Mississippi private non-industrial forest landowners. In: Proceedings of the Forest Fragmentation 2000 Conference. Sampson Group Inc. Alexandria, Va: 116-118.

Nebeker, T.E.; Hodges, J.D.; Karr, B.K; Moehring, D.M. 1986. Thinning practices in southern pines-with pest management recommendations. Tech. Bull. 1703. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 36 p.

Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. Journal of Agricultural Resources. 46(7): 627-638.

Traugott, T.A. 2000. Are my CRP pine trees ready to thin? Mississippi State University, Extension Service. Publication 2260. 7p.

USDA 1997. The conservation reserve program. U.S. Department of Agriculture. Farm Services Agency PA-1603. 40 p.

Wenger, K. F. 1984. Forestry Handbook 2d Ed. New York, NY: John Wiley and Sons, Inc., 1335 p.

Wood Quality/Technology

Moderator:

ALEX CLARK
USDA Forest Service

INFLUENCE OF THINNING AND PRUNING ON SOUTHERN PINE VENEER QUALITY

Mark D. Gibson, Terry R. Clason, Gary L. Hill, and George A. Grozdits[1]

Abstract—This paper presents the effects of intensive pine plantation management on veneer yields, veneer grade distribution and veneer MOE as measured by ultrasonic stress wave transmission (Metriguard). Veneer production trials were done at a commercial southern pine plywood plant to elucidate the effects of silvicultural treatments on veneer quality, yield, and modulus of elasticity. Forty-nine trees, totaling 1,312 ft^3, were selected from an intensively managed, 50-year-old loblolly pine (*Pinus taeda* L.) plantation at the Hill Farm Research Station of Louisiana State University at Homer, LA. Trees were selected from each of four treatments, pre-commercially thinned (PCT), pruned (PRN), pre-commercially thinned & pruned (PCT&PRN), and control (CTRL)[no thinning or pruning]. Twelve trees were selected per treatment, except for the PCT&PRN treatment that had thirteen trees. Each tree was felled, bucked into a log 17-foot-long plus trim, transported to the plywood plant, scaled on the log yard, bucked into two 101.5-inch-long peeler blocks (butt and top), conditioned in a drive-in steam chest (vat), rotary peeled into 1/8-inch-thick veneer using the plant's normal production process, then dried in a veneer drier. The length and width of full-sized veneer sheets, full-length random width strips (including half sheets) and half-length fishtails and strips were recorded to establish veneer yields. Full-sized sheets were graded visually according to U.S. Product Standard PS 1-83 in the green condition and after drying to establish veneer quality and drier degrades [A, B, C, D, and U (Utility) grades were identified] and by a Metriguard veneer tester for MOE determination. Five Metriguard groupings were assigned as follows: G1 (0-435ms, $2.44x10^6$ psi), G2 (436-475ms, $2.17x10^6$ psi), G3 (176-525ms, $1.86x10^6$ psi), G4 (525-700ms), and G5 (> 700ms). Only the G1, G2, and G3 groupings are used to produce laminated veneer lumber (LVL); hence, the G4 and G5 groupings were combined into a below grade category. When G1, G2, and G3 veneer classifications were combined, all intensive silvicultural treatments had a higher number of veneers qualify compared to the CTRL treatment in both butt and top blocks. Also, the number of veneers qualifying for LVL production in the top blocks exceeded that in the bottom blocks for all treatments. It is also interesting to note that the percentage of G1, G2, and G3 veneers in the top block exceeded that in the butt block in all treatments except the PRN treatment. Compared to the CTRL treatment, the PCT and PRN treatments had slightly faster average sound transmission times in veneers produced from both butt and top blocks, which corresponds to stiffer veneer. However, these faster transmission times did not significantly alter the MOE range (G-Rating). The percentages of qualifying G1, G2, and G3 veneers were about equal in each treatment, but the intensively managed trees produced more G-grade qualifying veneers. The top blocks produced more G-grade qualifying veneers in all except the pruned treatment. The average Metriguard grade for all treatments was G2. The relationship of MOE to visual grade is the subject of a future paper.

INTRODUCTION

Research priorities change, but one area that continues to be a high priority among government, non-industrial, and industrial organizations is growth and yield. Maximizing growth and yield relies on proper timing of silvicultural operations such as thinning and pruning. In loblolly pine plantations, these treatments can be instrumental in improving log and lumber volumes as well as dry veneer yields. Increased volume is important, but equally important, if not more so, is the grade of the veneer produced.

Lynch and Clutter (1998) state "grade is an essential determinant of value for southern pine plywood." Phillips and others (1979) reported that loblolly pine yielded 54 percent of the original log volume in dry usable veneer, while slash pine produced 55 percent. They also found loblolly pine produced 5 percent A-grade, 12 percent B-grade, 37percent C-grade, and 46 percent D-grade dry,

[1]Professor, Louisiana Forest Products Laboratory, School of Forestry, Louisiana Tech University, PO Box 10138, Ruston, LA 71272; Professor, LSU Agricultural Center, Hill Farm Research Station, 11959 Hwy 9, Homer, LA 71040; Production Analyst, Willamette Industries, Inc., PO Drawer 1100, Ruston, LA 71273-1100; Research Associate, Louisiana Forest Products Laboratory, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

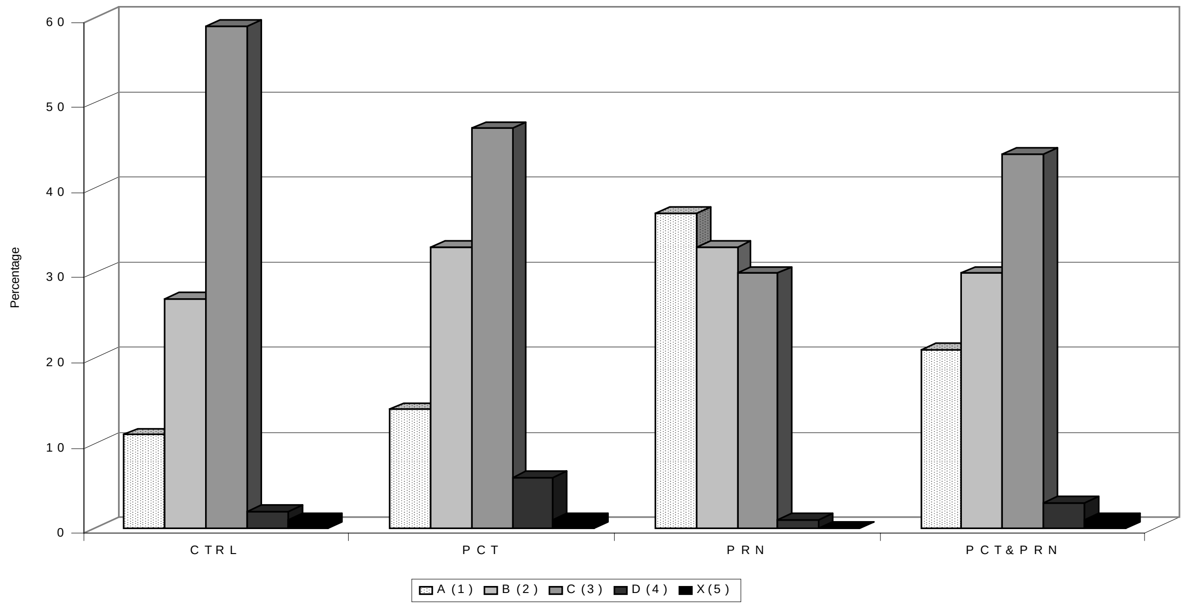


Figure 1—Dry veneer visual grade percentage yield by treatment (butt and top blocks combined).

untrimmed veneer. Woodfin (1973) reported that 55 percent of the total green plywood peeler block volume is recovered as dry, untrimmed veneer for four major western species. Funck and Sheffield (1985) indicated that dry veneer recovery was between 43 and 55 percent of peeler block volume. MacPeak and others (1987) showed dry veneer recovery of 48.3 percent for fast-grown 20- to 25-year-old loblolly pine, while "mill run" tree-length logs in a control group averaged 54.7 percent dry veneer recovery. Schroeder and Clark (1970) obtained a 60 percent dry veneer recovery when peeling 405 loblolly pine blocks. A more detailed description of the production process for rotary peeled veneer appears in Koch (1970, 1985).

This paper reports the results of a preliminary study designed to evaluate the effects of thinning and pruning on veneer yield, quality, and modulus of elasticity from an intensively managed, mature (50-year-old) loblolly pine plantation.

METHODS

Forty-nine trees were selected from an intensively managed, 50-year-old loblolly pine plantation located at the Hill Farm Research Station of Louisiana State University in Homer, LA. Trees were selected from each of four treatments, pre-commercially thinned (PCT) [average dbh 19.3 in], pruned (PRN) [average dbh 19.1 in], thinned & pruned (PCT&PRN) [average dbh 19.2 in], and control (CTRL) [no thinning or pruning, average dbh 15.6 in]. Twelve trees were selected per treatment, except for the thinned & pruned treatment that had thirteen trees. Each tree was felled, bucked into a 17-foot-long log plus trim, transported to the plywood plant, scaled on the log yard, bucked into two 101.5-inch-long peeler blocks (butt and top), conditioned in a drive-in steam chest (vat), rotary peeled into 1/8-inch-thick veneer using the plant's normal production process, then dried in their veneer drier. The length and width of full-sized veneer sheets (53-inch x 101.5-inch green and 51-inch x 101.5-inch dry), full-length random width strips (including half-sheets) and half-length fishtails and strips were recorded in both the green and dry condition to establish veneer yields. The facility produces veneer for a laminated veneer lumber (LVL) plant and for a commodity plywood sheathing plant. The plywood production

Table 1—Cubic-foot log volume and veneer recovery percentage by treatment

Treatment	Volume yield		
	Log	Veneer recovery	
		Green	Dry
	(ft^3)	(pct)	(pct)
Control	237	60	58
Pre-commercial thinned & pruned	373	69	66
Pre-commercial thinned	358	72	69
Pruned	344	64	61
TOTAL	1,312	67	64

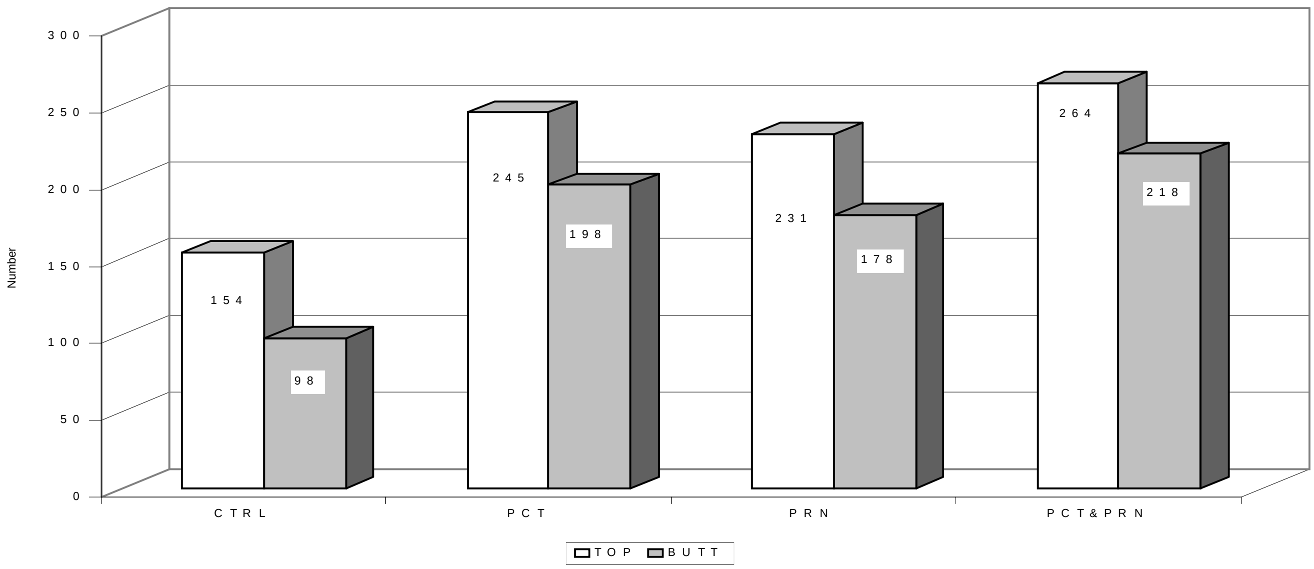


Figure 2—Number of full-sized veneer sheets qualifying for the G1, G2, and G3 grade classifications within each treatment for butt and top peeler blocks.

facility manufactures 245,000 ft^2 per 8-hour shift on a 3/8-inch basis. The LVL plant requires sorting the veneers by their modulus of elasticity values (MOE), which is done by a Metriguard Model 2600 FX veneer tester. The plywood plant requires visual grading for separation of core and face veneer as well as face veneer classification. Accordingly, the full-size sheets were visually graded according to U.S. Product Standard PS 1-83 in the green condition and after drying to establish veneer quality and drier degrades [A, B, C, D, and U (Utility) grades were identified] and by Metriguard for MOE determination. The correlation of veneer stiffness and LVL performance is constantly monitored by testing LVL samples and adjusting the acceptable ranges of veneer ultrasonic sound transmission rates. Five classifications (G1, G2, G3, G4, and G5) are assigned, although only veneers in the G1 through G3 groupings are actually used to produce LVL. The five groupings correspond to the following Metriguard grades, millisecond ranges, and MOE values: G1 (0-435ms, $2.44x10^6$ psi), G2 (436-475ms, $2.17x10^6$ psi), G3 (176-525ms, $1.86x10^6$ psi), G4 (525-700ms), and G5 (> 700ms). The G4 and G5 groupings were combined into a below grade category. A VHS camcorder was used to record both the Metriguard grade and the APA visual grade of the veneers. The plant provided a certified veneer grader whose grades were recorded onto the videotape. Metriguard readings and visual grades were transcribed from the videotape onto paper for entry into Microsoft®-Excel.

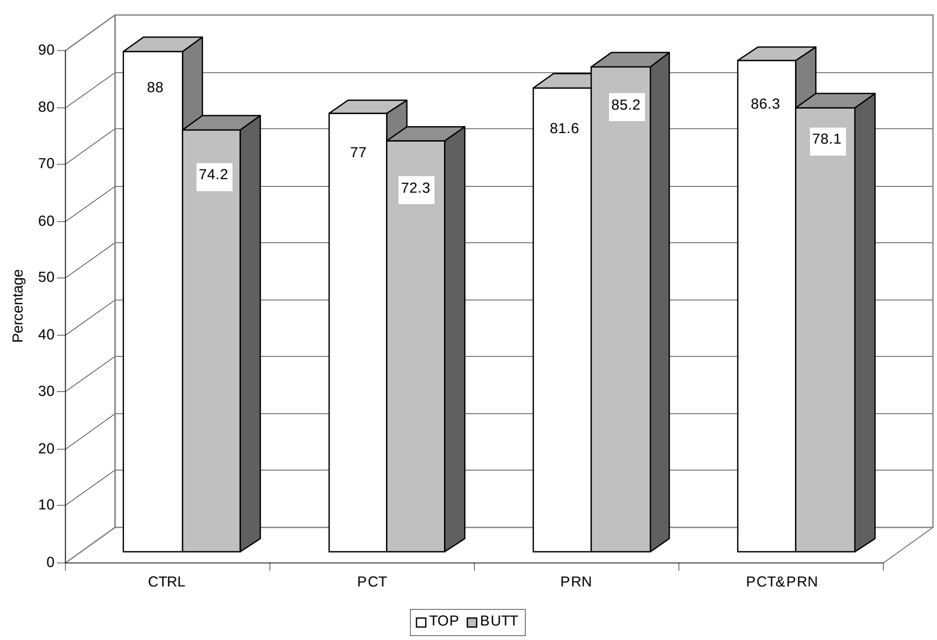


Figure 3—Percentage of full-sized veneer sheets qualifying for the G1, G2, and G3 grade classifications within each treatment for butt and top peeler blocks.

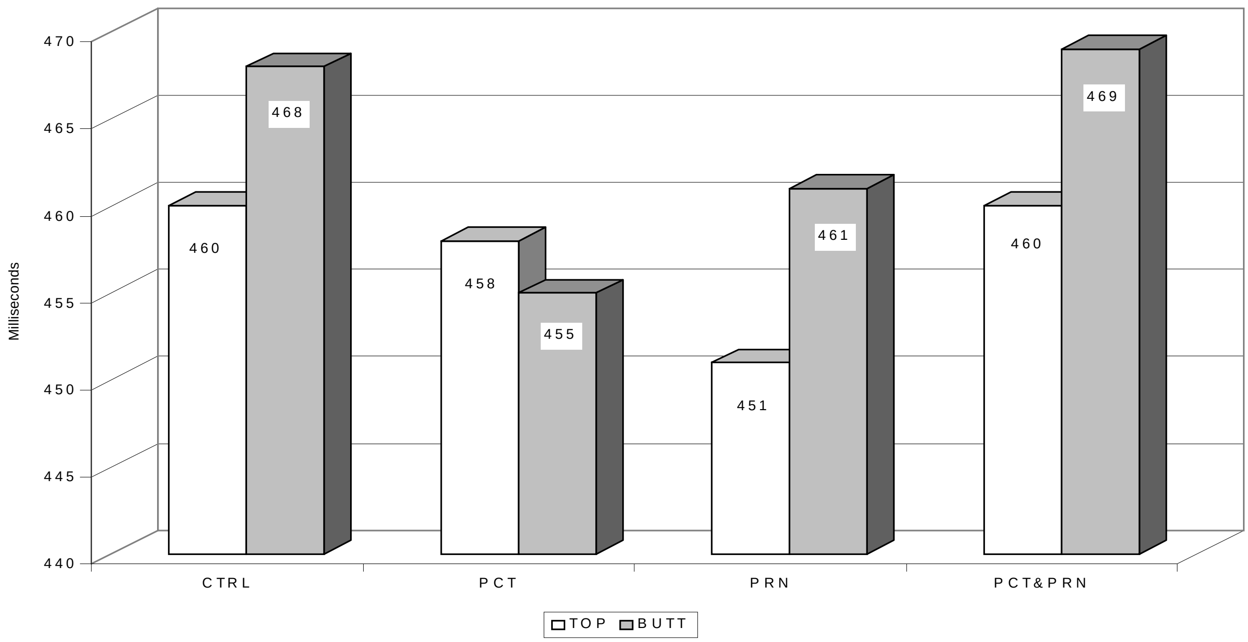


Figure 4—Mean metriguard millisecond transfer rate for full-sized veneer sheets in the G1, G2, and G3 grade classifications within each treatment for butt and top peeler blocks (faster transmission rates indicate stiffer veneers).

RESULTS AND DISCUSSION

Log Cubic-Foot Volume Yield

Table 1 shows the mean cubic-foot volume yield of the logs by treatment. The pre-commercially thinned and pruned treatment yielded 57percent more volume than the control. Pre-commercial thinning alone produced 51 percent more volume and pruning alone generated 45 percent more volume than the control. All silvicultural treatments produced volumes greater that of the control treatment; however, volume in the pruned treatment was the lowest for all silvicultural treatments. One possible explanation for this decrease is the volume of pruned logs was affected by loss of crown area and the consequent decrease in photosynthate. Hence, less material was available for wood formation. Because thinning was not done in combination with the pruning, the growth rate was not stimulated sufficiently and resulted in less volume production.

Dry Veneer Yield

Table 1 also shows the veneer recovery percentages of green and dry veneers by treatment, i.e., the percentage of the original log volume that became green or dry veneer. The pre-commercial thinning and pruning treatment produced 14 percent more dry veneer than the control. Pre-commercial thinning alone produced 19 percent more dry veneer than the control and pruning alone yielded 5 percent more dry veneer than the control. All silvicultural treatments improved veneer recovery above that of the control treatment.

Visual Grade Yield

Figure 1 illustrates the dry veneer visual grade percentage yields for each treatment. A higher percentage of A-grade and B-grade veneers were produced by the silvicultural treatments when compared to the control treatment. A-grade dry veneer yield in the pruned treatment was 236 percent greater than that for the control treatment. B & Better dry veneer grade yield in the pruned treatment was 69 percent of the total compared to 38 percent for the control treatment, a dramatic increase. The percentage of C-grade veneer was greatest in the control treatment.

Metriguard Classification

Figure 2 compares the butt peeler block with the top block for each of the treatments. When G1, G2, and G3 veneer categories were combined, all intensive silvicultural treatments had a higher number of veneers qualify compared to the CTRL treatment in both butt and top blocks. The number of qualifying veneers in the top blocks exceeded that of the bottom blocks for all treatments. Top peeler blocks have less taper than butt blocks and consequently have fewer round-up losses during veneer production.

The percentage of G1, G2, and G3 veneers in the top block exceeded that in the butt block in all treatments except the PRN treatment as shown in Figure 3. The percentages of qualifying G1, G2, and G3 veneers were about equal in each treatment (figure 3), but the intensively managed trees produced a greater number of G-grade qualifying veneers (figure 2). Again, the top blocks produced more G-grade qualifying veneers in all except the pruned treatment (figure 3).

Compared to the CTRL treatment, the PCT and PRN treatments had slightly faster average sound transmission times in veneers produced from both butt and top blocks, which corresponds to stiffer veneer (figure 4). However, these faster transmission times did not significantly alter the MOE range (G-Rating); hence, the average Metriguard grade for all treatments was G2.

CONCLUSIONS

Log Cubic-Foot Volume Yield

Log volume yield was highest in the pre-commercially thinned and pruned treatment (28 percent of the total volume, i.e., 57 percent more than the control) and lowest in the control treatment (18 percent of the total volume).

Dry Veneer Yields

Dry veneer volume yield (recovery) was highest for the pre-commercially thinned treatment, 69 percent compared to 58 percent in the control.

Visual Grade Yield

A-grade veneer yield in the pruned treatment was 236 percent greater than that for the control treatment. B & Better dry veneer grade yield in the pruned treatment was 69 percent of the total compared to only 38 percent for the control treatment.

Metriguard Classification

When G1, G2, and G3 veneer categories were combined, all intensive silvicultural treatments had a higher number of veneers qualify compared to the CTRL treatment in both butt and top blocks. The number of qualifying veneers in the top blocks exceeded that of the bottom blocks. Compared to the CTRL treatment, the PCT and PRN treatments had slightly faster average sound transmission times in veneers produced from both butt and top blocks, which corresponds to stiffer veneer. The average Metriguard grade for all treatments was G2.

Future Implications

The combined effects of increased log volume yield (45-57 percent above the control), higher dry veneer yields (5-19 percent above the control) and the dramatic increase in B & Better dry veneer grades (24-82 percent) support the potential for rotary peeling veneer mills to increase productivity, product yield and promote value-added products when they peel log supplies from intensively managed pine plantations.

ACKNOWLEDGMENTS

Funding for this study was provided by Willamette Industries, Inc.; Louisiana Tech University, School of Forestry; Louisiana Forest Products Laboratory; and LSU Ag Center, Hill Farm Research Station.

REFERENCES

Funck, J. W.; T. H. Sheffield. 1985. Veneer recovery and losses through the green-end clipper. Forest Products Journal 35 (11/12): 30-34.

Koch, P. 1972. Utilization of the Southern Pines. Vol. 2. Processing. Agric. Handb.420, Washington, D.C: U.S. Department of Agriculture, Forest Service. U. S. Government Printing Office.

Koch, P. 1985. Utilization of Hardwoods Growing on Southern Pine Sites. Vol. 2. Processing. Agric. Handb. 605. Washing ton D.C: U.S. Department of Agriculture, Forest Service, U. S. Government Printing Office, Washington, D. C.

Lynch, T. B.; M. L. Clutter. 1998. A system of equations for prediction of plywood veneer total yield and yield by grade for loblolly pine plywood bolts. Forest Products Journal 48(5): 80-88.

MacPeak, M. D.; L. F. Burkhart; D. Weldon. 1987. A mill study of the quality, yield and mechanical properties of plywood produced from fast-grown loblolly pine. Forest Products Journal 37(2): 51-56.

Phillips, D. R.; J. G. Schroeder; A. Clark III. 1979. Predicting veneer grade yields for loblolly and slash pine trees. Forest Products Journal 29(12): 41-47.

Schroeder, J.; A. Clark III. 1970. Predicting veneer grade yields for loblolly pine. Forest Products Journal 20(2): 37-39.

Woodfin, R. O., Jr. 1973. Wood losses in plywood production - four species. Forest Products Journal 23(9): 98-106.

EFFECT OF SILVICULTURE ON THE YIELD AND QUALITY OF VENEERS

Les Groom, Ray Newbold, and Jim Guldin[1]

Abstract—The structural and aesthetic value of wood is typically sacrificed in an attempt to meet demand. This paper addresses the financial and quality aspects of silvicultural choices as it relates to wood veneers. Five trees each were harvested from an uneven-aged stand and from the following even- aged stands: intensive plantation, conventional plantation, and natural regeneration. The 48-year old loblolly pine trees were peeled at a veneer mill and graded visually (plywood grades) and ultrasonically (LVL grades). The intensive plantation trees, pruned at an early age to produce a large, clear bole, possessed the lowest quality veneer, both in terms of visual and ultrasonic grade. Although these trees did produce large quantities of clear wood, the early, rapid growth rates resulted in a exaggerated conical shape and thus a large slope of grain. The most desirable veneers came from those trees with a modest growth rate during the juvenility period—from the natural regeneration and uneven aged stands.

INTRODUCTION

The primary objective of most current timber management strategies is optimization of wood fiber volume, generally at the expense of wood quality. A shift in public values coupled with harvesting restrictions and the unavailability of old-growth timber has resulted in a higher percentage of the wood basket being supplied by plantation and intensively managed timber stands. The trees which come from these plantation forests are harvested at a young age when compared to virgin and old growth trees, and will thus contain a higher percentage of juvenile wood and invariably lessened physical and mechanical lumber properties.

The effect of silvicultural treatments on the physical properties of wood has been extensively studied. Thinning and fertilization have been shown to significantly alter overall wood specific gravity (Choong and others, 1989; Lear and others, 1977; Cown and McConchie, 1981), earlywood/latewood specific gravity distribution (Choong and others, 1989; Crist and others, 1977), knot size, location, and quantity (Whiteside and others, 1977; Guldin and Fitzpatrick, 1991), tree form (Guldin and Fitzpatrick, 1991), fiber length (Cown and McConchie, 1981; Crist and others, 1977), and juvenile wood formation (Zobel and VanBuijtenen, 1989; Ruark and others, 1991). Although numerous studies have inferred relationships between physical and mechanical wood properties, in actuality the correlations between physical and mechanical properties are low. The best correlation exists between specific gravity and stiffness, with correlation coefficients generally around 0.5 (Schroeder and Atherton, 1973; Senft and others, 1962). Similar correlation coefficients exist between specific gravity and strength (Doyle and Markwardt, 1966; Senft and others, 1962). Thus, although the effect of silvicultural practices on physical properties is somewhat understood, the stiffness and strength of the resulting wood cannot be determined from these physical properties.

The response of mechanical properties to silvicultural treatments is less understood. Bendtsen and Senft (1986) looked at mechanical and anatomical properties in individual growth rings of plantation-grown eastern cottonwood and loblolly pine and found that a large percentage of juvenile wood exists along with a marked decrease in stiffness and strength for the first 10-15 growth rings. Senft and others (1986) found similar findings for a natural stand of 60-year-old Douglas-fir trees. Similar studies have also been conducted (Moody, 1970; Pearson and Gilmore, 1971; Yamamoto and others, 1976), but their conclusions were limited to one type of silvicultural treatment.

This primary objective of this paper is to establish relationships between silvicultural regimes and the one area lacking in the literature: veneer quality. This paper will define some of the relationships between silviculture and veneer quality and value.

METHODS

Five loblolly pine (*Pinus taeda L.*) trees were selected and felled from forest stands subject to different reproduction cutting methods at the Crossett Experimental Forest, Crossett, Arkansas. The reproduction cutting methods investigated in this study are: (a) intensive plantation (the Sudden Sawlog study), (b) conventional plantation (Methods of Cutting study), (c) even-aged natural regeneration (Methods of Cutting Study), and (d) uneven-aged (Good

[1]Research Scientist, Southern Research Station, 2500 Shreveport Hwy, Pineville, LA 71360; Professor, Louisiana Tech University, Ruston, LA 71272; Research Forest Ecologist, Southern Research Station, 523 Reserve St, Hot Springs, AR 71902, repectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Average harvested tree statistics from each silvicultural regime

	Intensive plantation	Conventional plantation	Natural regeneration	Uneven-age 50-year trees
No. of Observations	5	5	5	5
Height (ft.)	94.2	93.8	98.6	88.6
Ht. base live crown	41.2	57.0	60.2	40.2
Age (years)	48	48	48	47
Average dbh (in.)	21.1	15.3	16.4	16.4
BAF10 (sq. ft.)	90	118	76	72

Farm Forestry Forty). A thorough description of each stand can be found in Baker and Bishop (1986). In the Sudden Sawlog study, at age 48 the stand had a basal area of 101 sq. ft, and an average dbh of 21.5 inches. The stand was thinned at age 9 to 100 trees per acre (tpa), and at ages 19, 24, and 27 to a final stand density of 41 tpa. The stand was mowed biennially and trees were pruned to 34 feet. The conventional plantation stand was 48 years old, had a basal area of 143 sq. ft. and an average dbh of 15.1 inches. The stand was thinned every 3 years from ages 12 to 30 to a final stand density of 116 tpa. There was no pruning or understory control. The natural regeneration stand at harvest was 48 years old, had a basal area of 90 sq. ft, and an average dbh of 16.3 inches. The stand was originally clearcut and allowed to regenerate naturally. The stand was thinned to a basal area of 80 sq. ft. in at ages 37, 42, and 47. The trees were not pruned, with understory control via prescribed burning at ages 37, 42, and 47. The uneven-aged stand varied from seedlings to approximately 100 years of age. The basal area at time of specimen selection was 65 sq. ft. The stand was thinned to a basal area of 60 sq. ft. at ages 37, 42, and 47. Trees harvested from this stand are traditionally dominant and co-dominant. The trees selected for this study were approximately 48 years of age, regardless of dominance status.

Trees with crooked boles were eliminated from the selection process, thus minimizing the presence of reaction wood. Immediately upon felling, the bole was bucked into 10-foot lengths starting from the stump and proceeding to a 4-inch diameter top. The logs were transported to a local veneer mill, peeled, dried, and then passed through a Metrigard stress-wave timer for determination of transit time. The stacks of veneer were transported to the Southern Research Station, Pineville, LA for visual grading by an American Plywood Association certified grader.

RESULTS AND DISCUSSION

A summary of the harvested tree statistics is shown in table 1. The height of the even-aged trees were all approximately 95 feet whereas the competition of dominant trees in the even-aged stand limited the height of the even-aged trees to 88 feet. The most dramatic differences in the stands were dbh and height to live crown. The greater spacing and understory control allocated the intensive plantation trees resulted in much larger dbh growth. These factors, along with pruning to a minimum 34 feet height, also resulted in the lowest height to live crown. Thus, although the volume of wood per tree from the intensive plantation stands was greater than the other stands, only the lower 40 percent of the bole contained potential knot-free wood. The other even-aged stands had live crowns approximately 60 percent of the total tree height.

The quantity of veneers that resulted from the 5 trees from each stand is shown in figure 1. The average number of veneers that came from each tree in the intensive plantation, conventional plantation, natural regeneration, and uneven-age stands was 126, 65, 81, and 62, respectively.

The visual quality of the veneers and thus their usefulness in the manufacture of structural plywood is summarized in table 2. The trees from the plantation stands produced veneer that was inferior in visual grade to the corresponding trees in the natural regeneration and uneven-aged stands. Approximately 60 percent of the veneers from the intensive plantation stand were graded as D or X. This is due to the resulting knots from the extremely large limbs in this stand. The conventional plantation stand had much fewer D or X grade veneers, but 66 percent of all veneers from this stand were C grade. The natural regeneration and uneven-aged stand produced the best visual grade veneers, with approximately 32 percent of all veneers falling into the A or B grade. This is due primarily to the clear boles in conjunction with very little taper.

Table 2—Percent yield for all veneers from each of the silvicultural regimes based on visual grade

	(Percent yield per grade)					
Management type	A	B	Cp	C	D	X
Plantation: Intensive	3.0	15.5	9.0	12.4	***50.7***	***9.4***
Plantation: Conventional	2.5	9.6	10.2	***65.7***	11.4	0.6
Even Age: Natural regeneration	***16.1***	***13.9***	7.7	35.1	27.0	0.2
Uneven Age: 50-year old trees	***14.3***	***18.6***	7.8	47.9	11.4	0.0

The percent yields of veneers from various stands as graded by transit time via a stress wave timer are summarized in table 3. These values are indicative of veneer stiffness and are essential in the layup of structural products such as laminated veneer lumber and to a lesser degree oriented strand board. A trend similar to the visual grades is observed: the intensive plantation possessing the highest percentage of low stiffness veneers, conventional plantation containing mostly middle grades, and the natural regeneration and uneven-aged stands producing the highest percentage of high stiffness veneers.

The quality of the veneers for each stand varies greatly from the pith to the bark and with vertical location within a tree. A summary of veneer visual grade and veneer stiffness as a function of location within a tree are, respectively, summarized in figures 2 and 3. Although trees from the intensive plantation stand did produce some high quality veneers, these high value veneers were limited to a small region below the live crown and some distance from the juvenile core. The juvenile core and almost all of the veneers at or above the live crown in the intensive plantation stand were of poor visual and structural quality.

From a forest management economics perspective, the quantity and quality of veneer production must translate to per-acre values. The number of trees per acre, their size, and the timing of the stand cost and revenue stream establish the financial return to investment. Dollar values for dry veneer by grade were solicited from buyer sources and reporting services. These values were reduced by harvesting, transportation, and manufacturing costs to establish the value for the expected veneer production from standing stumpage. Stand inventory records were used to reconstruct the diameter distributions and trees per acre for each silvicultural treatment. Tree values were based on their expected veneer yields and financial statistics were calculated. Forest management costs were established using published sources and personal communication (Clason 2000, Dubois and others 1999, Watson and others 1987, Yoho and others 1971).

Table 3—Percent yield for all veneers from each of the silvicultural regimes based on ultrasound propagation times.

	Percent yield per Metrigard (t) range				
Management type	<400	400-469	470-539	540-609	>610
Plantation: Intensive	0.0	11.9	43.3	***36.0***	***8.8***
Plantation: Conventional	0.0	32.4	***49.8***	15.0	2.8
Even Age: Natural regeneration	0.0	***41.3***	35.1	21.5	2.0
Uneven Age: 50 year-old trees	***0.7***	***41.7***	41.4	15.3	1.0

Figure 1—Veneers peeled from 5 trees each of the following silvicultural regimes: (1) intensive plantation, (2) conventional plantation, (3) natural regeneration, and (4) uneven age.

The lowest cost silvicultural system (in dollars expended) was the natural regeneration at $268.97 per acre. The highest cost was the sudden sawlog system at $705.47. The cost for the conventional plantation was $288.23 and for the uneven-aged stand was $358.22. In the case of the uneven-aged stand, the initial value of the stand which produced the revenue stream was also counted as a cost (capital investment).

In terms of internal rate of return (IRR), three of the four systems were similar in financial returns to the capital invested over the 50-year period. The two plantations averaged 9.6 percent and the naturally regenerated stand averaged 10.1 percent IRR. These were in contrast to the uneven-aged system which returned an average of 5.8 percent. The large tree diameters boosted the total veneer yield for the sudden sawlogs, though it was mostly D-grade. The veneer yield from the other three stands was comparable, but the clearcut/natural regeneration stand had the advantage of low cost regeneration, and the uneven aged stand had the disadvantage of high capital investment in the form of initial growing stock.

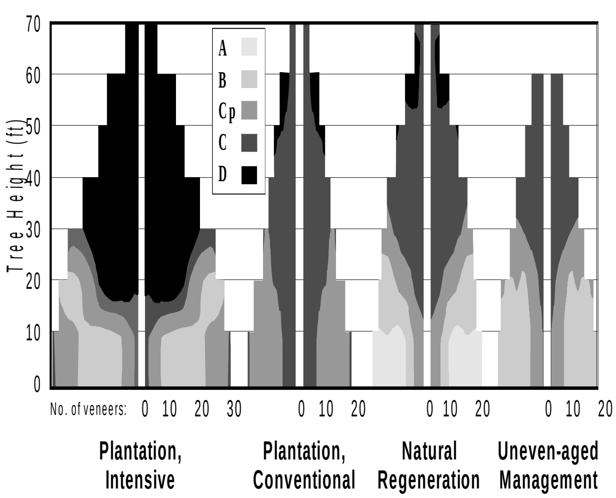


Figure 2—2-dimensional maps of veneer visual grade by location within a tree. Maps are based on the averages of 5 trees per silvicultural regime.

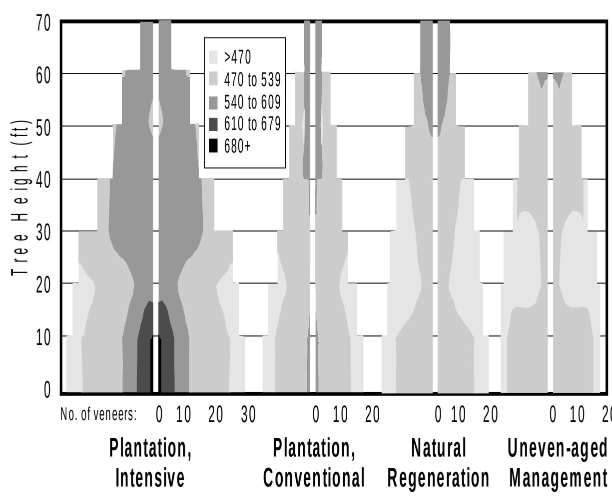


Figure 3—2-dimensional maps of ultrasound transit time, shown in microseconds, for veneers by location within a tree. Due to the inverse relationship, lower transit times correspond to stiffer veneers. All maps are based on the averages of 5 trees per silvicultural regime.

Even-aged systems reflected the natural presence of loblolly pine in the early successional stages of the southern forest and seemed to be the most efficient silvicultural system for management based on financial returns. How those forests are regenerated and managed reflect the objectives of the landowner in regard to the outputs desired. There are legitimate reasons for choosing an uneven-aged system (Baker and others 1996), however, the higher proportion of good veneer grades is offset by the investment carried in growing stock unless careful attention is given to those growing stock levels. As structural grades of plywood continue to be replaced by oriented strand board (OSB), the economics associated with veneer production will change to favor higher grades and lower the relative value of the lower grades, thus affecting the returns of the silvicultural systems accordingly.

CONCLUSIONS

The quantity and quality of veneers was shown to be a function of silvicultural regime as well as location within a tree. Intensively-managed plantation stands produced the greatest number from each tree, averaging 126 veneers per tree. Although the trees were pruned to ensure a clear bole to 34 feet, the resulting veneers were of very poor quality, due to both excessive taper and a low live crown with large limbs. The trees from the conventional plantation stand only averaged 65 veneers per tree. The veneers were of better quality than the intensively-managed plantation stand, but still of mediocre quality. Trees peeled from natural regeneration and uneven-aged stands were of the best quality, averaging 81 and 62 veneers per tree, respectively. The veneers from these 2 stands produced the highest proportion of visual grades as well as the greatest proportion of high stiffness veneers.

The economics of forest stand management, in addition to individual tree values, also incorporate tree populations on a per-acre basis. Outcomes on which management decisions will be based are affected by investments and harvest schedules, as well as market values of the veneer grades produced.

LITERATURE CITED

Baker, J.B. and L.M. Bishop. 1986. Crossett Demonstration Forest Guide. USDA Forest Service General Report R8-GR 6. 55 p.

Baker, J.B.; M.D. Cain, J.M. Guldin, P.A. Murphy, and M.G. Shelton. 1996. Uneven-aged silviculture for the loblolly and shortleaf pine forest cover types. Gen. Tech. Rep. SO-118. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 65 p.

Bendtsen, B.A.; J. Senft. 1986. Mechanical and anatomical properties in individual growth rings of plantation-grown Eastern cottonwood and loblolly pine. Wood and Fiber Science 18(1): 23-28.

Choong, E.T., P.J. Fogg, and E. Shoulders. 1989. Effect of cultural treatment and wood-type on some physical properties of longleaf and slash pine wood. Wood and Fiber Science 21(2): 193-206.

Clason, Terry R. 2000. Forester, LSU AgCenter, Hill Farm Research Station, Homer, LA. Personal communication.

Cown, D.J.; D.L. McConchie. 1981. Effects of thinning and fertiliser application on wood properties of Pinus radiata. New Zealand Journal of Forestry Science 11(2): 79-91.

Crist, J.B., D.H. Dawson; J.A. Nelson. 1977. Wood and bark quality of juvenile jack pine and eastern larch grown under intensive culture. Tappi conference papers: Forest Biology-Wood Chemistry Conference, Madison, WI. 211-216.

Doyle, D.V.; L.J. Markwardt. 1966. Properties of Southern pine in relation to strength grading of dimension lumber. USDA Forest Service Research Paper FPL 64. Forest Products Laboratory, Madison, WI.

Dubois, M.R.; K. McNabb; T.J. Straka. 1999. Costs and cost trends for Forestry Practices in the South. Forest Farmer 32nd Manual Edition. 3-8.

Guldin, J.M.; M.W. Fitzpatrick. 1991. Comparison of log quality from even-aged and uneven-aged Loblolly Pine stands in South Arkansas. Southern Journal of Applied Forestry 15(1): 10-17.

Moody, R.C. 1970. Tensile strength of fingerjoints in pith-associated and nonpith-associated southern pine lumber. USDA Forest Service Research Paper FPL 138. Forest Products Laboratory, Madison, WI.

Pearson, R.G.; R.C. Gilmore. 1971. Characterization of the strength of juvenile wood of loblolly pine (Pinus taeda L.). Forest Products Journal 21(1): 23-30.

Ruark, G.A.; J.R. Saucier; R.G. Campbell. 1991. Managing dense, seed-origin Loblolly stands to utilize the favorable juvenile wood core for sawlog production: A case study. Southern Journal of Applied Forestry 15(1): 5-9.

Schroeder, G.A.; G.H. Atherton. 1973. Mechanical properties of utility grade redwood 2x4 studs. Project No. F914. Forest Research Laboratory, Oregon State University, Corvallis, OR. May 1973.

Senft, J.F.; M.J. Quanci; B.A. Bendtsen. 1986. Property profile of 60-year-old Douglas-fir. In Proceedings, A Technical Workshop: juvenile wood - what does it mean to forest management and forest products. Forest Products Research Society. 17-28.

Senft, J.F.; S.K. Suddarth; H.D. Angleton. 1962. A new approach to stress grading of lumber. Forest Products Journal 12(4): 183-186.

Van Lear D.H.; J.R. Saucier; J.G. Williams. 1977. Growth and wood properties of longleaf pine following silvicultural treatments. Soil Science Society of America Journal 41(5): 989-992.

Watson, W.F.; T.J. Straka; S.H. Bullard. 1987. Costs and Cost Trends for Forestry Practices in the South. Forest Farmer 26th Manual Edition, 28-34.

Whiteside, I.D.; M.D. Wilcox; J.R. Tustin. 1977. New Zealand Douglas-fir timber quality in relation to silviculture. New Zealand Journal of Forestry 22(1): 24-44.

Yamamoto, H.; M. Takahashi; N. Kawaguchi. 1976. The strength properties of plantation-grown todomatsu. Journal of the Hokkaido Forest Products Research Institute 4(291): 1-5.

Yoho, J.G., G.F. Dutrow and J.E. Moak. 1971. What it Costs to Practice Forestry—Costs and Cost Trends in the South. Forest Farmer, March issue, 42-50.

Zobel, B.J. and J.P. Van Buijtenen. 1989. Wood Variation - Its Causes and Control. Springer Series in Wood Science (Editor T.E. Timell). 415 p.

RAPID ASSESSMENT OF THE FUNDAMENTAL PROPERTY VARIATION OF WOOD

Chi-Leung So, Leslie H. Groom, Timothy G. Rials, Rebecca Snell, Stephen S. Kelley, and Robert Meglen[1]

Abstract—Genetic variation, site conditions, silvicultural treatments, seasonal effects, and their complex interaction are all vitally-important factors accounting for the variability and quality of the raw material produced - wood. Quality can be measured in several ways that generally influence the end use. The most desirable measure is the fundamental properties. The physical properties and strength characteristics at selected locations in the bole have been determined for three loblolly pine trees obtained from the Crossett Experimental Forest (Crossett, AR). The range and variation of properties within and between the trees has been summarized in the form of wood property maps. The creation of such property maps via traditional test methods require much time and expense. However, a new rapid assessment technique combining near infrared (NIR) spectroscopy with multivariate statistical techniques to predict these fundamental properties has shown great potential. This paper introduces the application of this developing methodology to wood quality issues by highlighting early results from a larger program that will define the range of properties for southern pine. The results from the standard test methods have been compared with those predicted from NIR spectra/multivariate analysis, and have been shown to provide excellent correlations.

INTRODUCTION

An improved understanding of genetic factors and silvicultural treatments on the chemical, physical, and mechanical properties of wood is important for producing raw materials that are optimized for specific material systems. Paper and pulp operations require sensitive measurement of chemical composition of wood chips to control processing conditions. It is reasonable to assume that manufacturers of wood composite products can derive similar benefits from data on physical and mechanical properties of the wood. This type of information is not routinely available because of the time and expense required to obtain the data.

Recent research has addressed the issue of rapid assessment methods that are capable of affordably evaluating fundamental wood characteristics. Near infrared (NIR) reflectance spectrometry (1,000 - 2,500 nm, 10,000 - 4,000 cm^{-1}) combined with multivariate statistical techniques has now been demonstrated to provide spectra of sufficient quality to permit chemical analysis of solid wood without sample preparation (Schimleck and others 1997; Meder and others 1999). The application of multivariate analysis to the NIR spectra of wood has reduced much of the problem of overlapping signals from the three main polymer constituents: cellulose, hemicellulose and lignin (Wallbacks 1991). NIR spectra have also been used to provide quantitative, non-destructive measurement of physical properties such as density (Meder and others 1999).

Several studies have been performed comparing the use of near infrared (NIR) and Fourier transform infrared (FTIR) with multivariate analysis for predicting chemical composition (Schultz and Burns 1990; Wallbacks and others 1991a,b; Meder and others 1999). It was observed that although both NIR and FTIR could be used to predict chemical composition, it was the NIR spectra which generally produced better correlations and was clearly the simpler and much faster technique.

This technique found acceptance in the pulp and paper industry and has been used to predict paper properties from the spectra of pulp (Wallbacks and others 1991a,b) as well as paper ageing studies in which the age of paper in service could be estimated (Ali and others 2001). Similarly this technique has been gaining use for online process monitoring in particleboard manufacture. In particular, it can facilitate the reduction in standard deviation of the board quality by adjusting the process settings accordingly, thus leading to substantial cost savings (Engstrom and others 1998; Johnsson and others 2000).

MATERIALS AND METHODS

The trees selected in this study are part of a larger program to study the variability and development of properties for southern pine. Three trees were selected from each site. The majority of this paper is concerned with a set of 55-yr old loblolly pine (*Pinus taeda* L.) trees felled from a natural regeneration stand in the Crossett Experimental Forest, Crossett, AR. Periodic understory control was conducted via a series of prescribed burns. Trees were also collected in

[1]Research Scientist, Research Scientist, Project Leader, USDA-Forest Service, Southern Research Station, Pineville, LA; Research Scientist, BioComposites Center, Bangor, Wales; Senior Chemist, Senior Chemist, National Renewable Energy Laboratory, Golden, CO, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

South Carolina and two sites in Mississippi for comparisons. A set of 15-yr old loblolly pine trees was collected from a rapid growth experimental plot near Summerville, SC, in which a 6 x 6 ft spacing was chosen for the first 5 years and then 12 x 12 ft thereafter. Three extremely-fast grown loblolly pine trees were chosen from a seed orchard in Eastabuchie, MS. These were felled from a 29-yr old clonal stand in which the conditions were primed for cone production. The last set in this study is a set of 30-yr old slash pine (*Pinus elliottii* Engelm) trees, grown on a wet site, in DeSoto National Forest, MS. Important tree data such as the height, diameter at breast height (d.b.h.) and height to live crown are listed in table 1.

Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)

The bending specimens were taken from disks 14 inches in height that were cut at 15 ft separations along the tree height. Two parallel cuts were made along the disks, north to south, approximately 0.5 inches either side of the pith. These slabs were further cut according to the ring of interest, in which one ring either side was included, such that the specimen was 3 rings high and 1 inch wide. The specimens were cut to 12 inches in length for testing, under three-point bending, in an Instron testing machine. Care was taken to avoid any regions with defects, such as knots, where possible. A 1-inch cut-off piece was used for specific gravity testing.

Near Infra-Red (NIR) Spectroscopy

NIR spectra were obtained using a FieldSpec FR (Analytical Spectral Devices Inc., Boulder, CO) at wavelengths between 350 and 2500 nm. Thirty scans were collected and averaged into a single spectrum. Two spectra were collected for each specimen.

Multivariate Analysis

Multivariate analysis of the NIR data was performed using The Unscrambler® vsn. 7.5 software package (CAMO, Corvallis, OR). Partial least squares (PLS) analysis was conducted on the spectra after averaging. The models were generated using full cross-validation; this is a method in which one sample is systematically removed from the data set; a model is created from the remaining samples, and this model is used to predict a value for the extracted sample. This process is subsequently repeated for all remaining samples (Martens and Naes 1992). No further manipulation of the spectral data was employed.

Table 1-–Summary of the tree height, diameter at breast height, and height to live crown for the trees

Site	Tree No.	Height of Tree, ft.	D.B.H., in.	Height to Live Crown, ft.
Crossett, AR	1	92.7	16.4	73.6
	2	100.5	18.8	72.5
	3	98.1	20.9	78.6
Summerville, SC	1	59.7	10	24.3
	2	61.0	10.3	29.0
	3	59.3	9.8	29.5
Eastabuchie, MS	1	70.0	22.5	27.5
	2	75.0	23.3	26.0
	3	65.0	23.6	15.0
Hattiesburg, MS	1	47.5	6.2	31.0
	2	64.4	8.7	38.0
	3	56.5	8.4	45.7

RESULTS AND DISCUSSION

Tree Property Maps

Three trees were collected from each location and each of the following tree property maps (figures 1 through 4) is an average of the three trees taken. These tree property maps show the variation in a particular property within the tree. Figure 1 shows the variation of specific gravity in the 55-year-old trees from the Crossett site. The specific gravity for a given growth ring increases with tree height. The base of the tree provides the highest values of specific gravity, with the lowest derived within the juvenile core.

Although there exists a relationship between specific gravity and modulus of elasticity (MOE), this relationship is not strong as can be seen in figure 2. MOE appears to be more closely associated with juvenility, as pith-associated wood is more compliant than the corresponding mature wood. That is because MOE is more closely associated with microfibril angle (MFA) than with specific gravity (Megraw 1985). This strong relationship between stiffness and MFA also exists for strength as can be seen in figure 3.

The variation of MOE with tree location is not a constant from stand to stand (figure 4). Interactions such as live crown, specific gravity, and MFA result in a 3-dimensional maturation process that affects subsequent mechanical properties. These figures clearly show there is a large property variation within the tree. Thus, taking increment cores at breast height, a common technique, cannot be taken to representative of the whole tree.

Near Infra-Red (NIR) Spectroscopy

The NIR spectra of juvenile (rings < 8) and mature (rings > 24) wood obtained from loblolly pine, between 350 – 2500 nm, is shown in figure 5. It is clear to see that differences cannot be noted visually; the characteristic peaks show broad overlapping absorption bands arising from secondary overtones and combinations X-H stretching vibrational modes. NIR is, most importantly, sensitive to hydrogen bonding, thus making it very applicable to wood. The use of multivariate statistical techniques improves the extraction of information from the spectra, revealing any differences.

Multivariate Analysis

Figure 6 shows a prediction plot for the specific gravity in which the abscissa is the “true” specific gravity determined from standard test methods and the ordinate is the “NIR-predicted” specific gravity from the NIR spectra and multivariate analysis. It is clearly observed that the data follow the 1:1 line very well with a r-value of 0.82. Good correlations were also obtained for the mechanical properties as shown in figure 7 for the modulus of elasticity (MOE) and figure 8 for the modulus of rupture (MOR) with resultant r-values of 0.88 and 0.87 respectively. These findings are

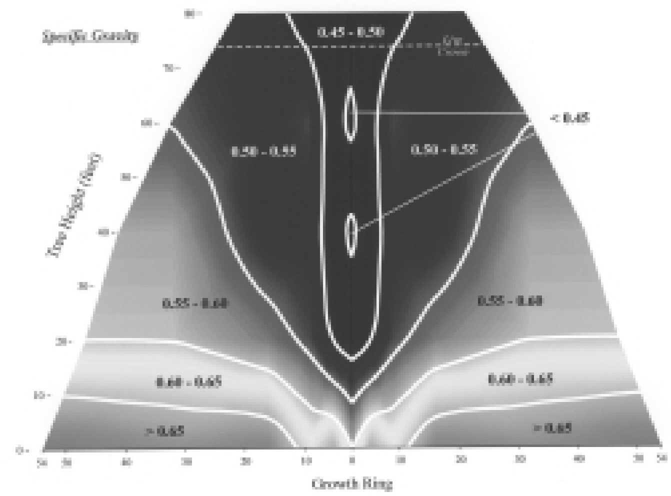


Figure 1—Specific gravity maps for trees harvested from 55-year-old loblolly pine (Crossett, AR).

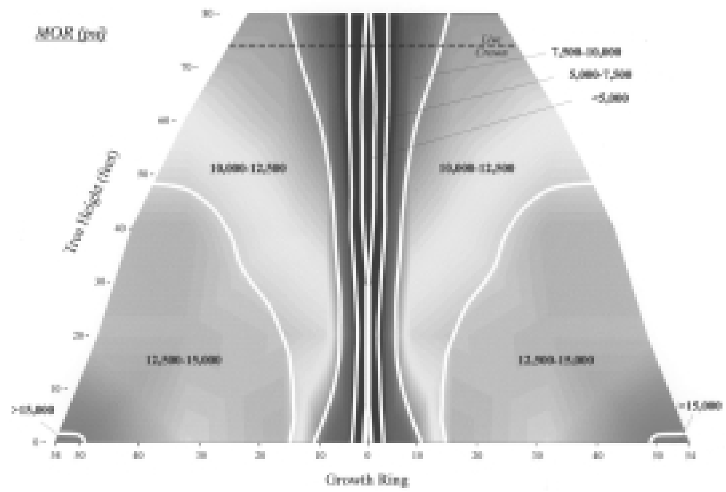


Figure 3—Modulus of rupture (MOR) maps for trees harvested from 55-year-old loblolly pine (Crossett, AR).

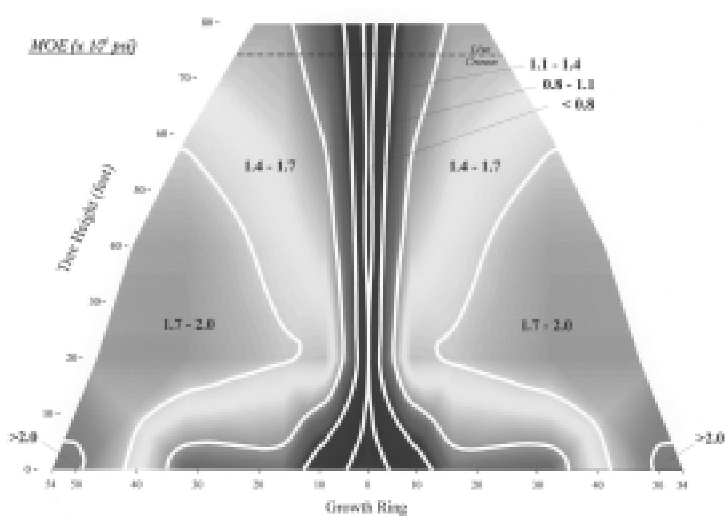


Figure 2—Modulus of elasticity (MOE) maps for trees harvested from 55-year-old loblolly pine (Crossett, AR).

consistent with Engstrom and others (1998) who obtained a similarly good correlation of 0.9 for particleboard MOR.

CONCLUSIONS

Property mapping of trees clearly reveals large variations with location within the tree. This was further extended to compare the MOE variation within trees from different stands. Naturally, differences were observed between the maps, with particular interest in the differences in their magnitude and their patterns. These maps show how growth conditions affect property variation within a tree and can be applied to silvicultural treatments to improve tree properties; however, the construction of such maps requires much time and expense with traditional test methods.

It has been shown that NIR spectroscopy, in conjunction with multivariate analysis, can be used to predict fundamental wood properties with excellent results, and in a much smaller time scale than by traditional testing. With further advances in technology, the development of a hand-held portable field unit capable of assessing all major wood properties on standing timber may be possible.

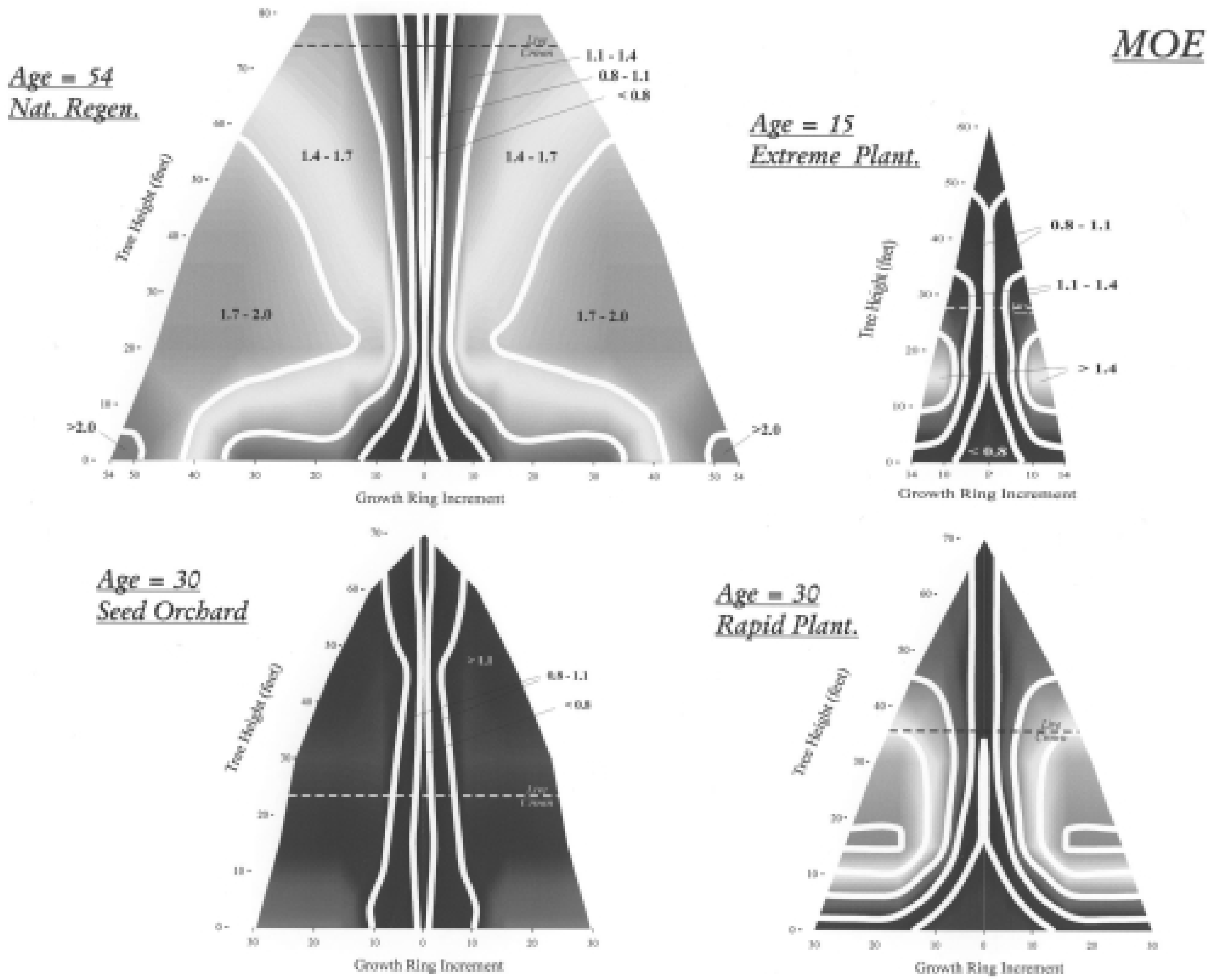


Figure 4—Modulus of elasticity (MOE) maps for trees harvested from (a) 55-year-old loblolly pine (Crossett, AR); (b) 15-year old-loblolly pine (Summerville, SC); (c) 30-year-old, seed orchard, loblolly pine (Eastabuchie, MS); and (d) 30-year-old slash pine (Hattiesburg, MS).

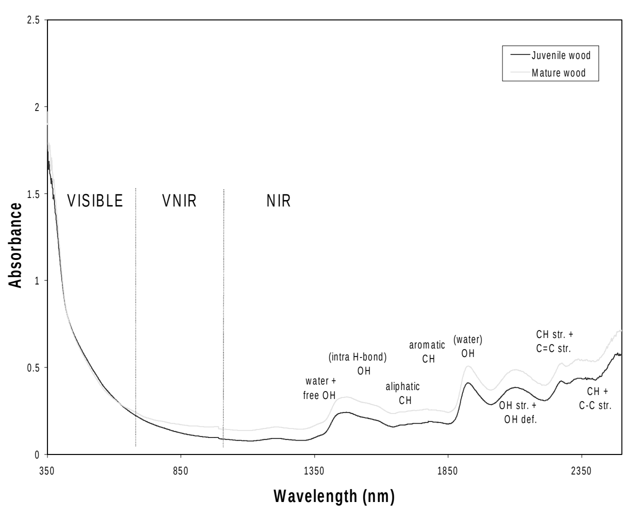


Figure 5—NIR spectra of juvenile and mature wood obtained from loblolly pine in the range of 350 – 2500 nm.

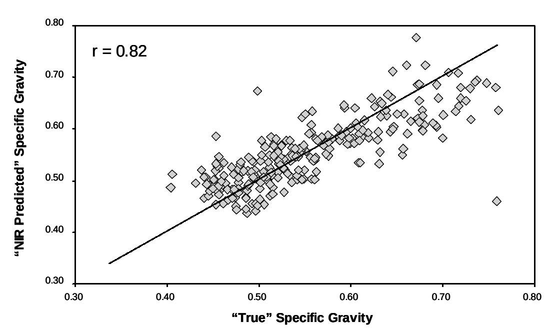


Figure 6—Comparison of "NIR-predicted" vs. "true" values for specific gravity.

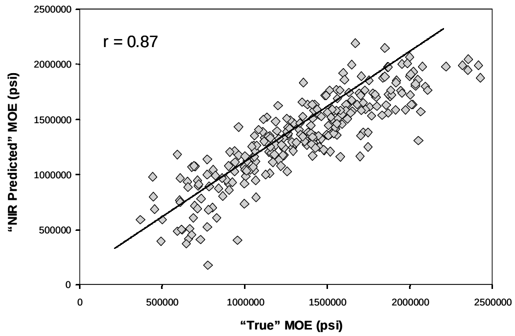


Figure 7— Comparison of "NIR-predicted" vs. "true" values for modulus of elasticity (MOE).

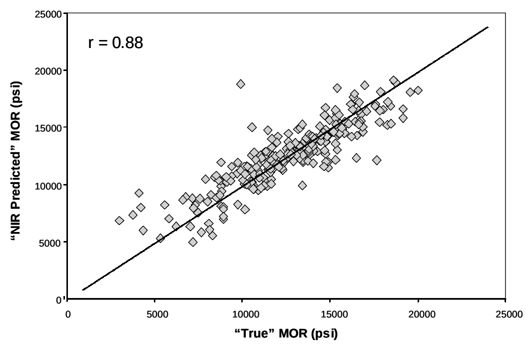


Figure 8—Comparison of "NIR-predicted" vs. "true" values for modulus of rupture (MOR).

LITERATURE CITED

Ali, M.; Emsley, A.M.; Herman, H.; Heywood, R.J. 2001. Spectroscopic studies of the aging of cellulosic paper. Polymer. 42: 2893-2900.

Engstrom, B.; Johnson, B.; Hedquist, M.; Grothage, M.; Sundstrom, H.; Arlebrandt, A. 1998. Process modeling system for particleboard manufacturing, incorporating near infrared spectroscopy on dried wood particles. In: Proceedings of the second European panel products symposium, Llandudno, Wales, 21-22 October 1998. 107-114.

Johnsson, B.; Wallsten, P.; Renmarker, P. 2000. BoardModel – a new NIR-base process modeling system for wood panels. In: Proceedings of the 34th international particleboard / composite materials symposium, Pullman, WA, 4-5 April 2000. 97-100.

Martens, H.; Naes, T. 1992. Multivariate calibration. New York: John Wiley. 419 p.

Meder, R.; Gallagher, S.; Mackie, K.L.; Bohler, H.; Meglen, R.R. 1999. Rapid determination of the chemical composition and density of *Pinus radiata* by PLS modeling of transmission and diffuse reflectance FTIR spectra. Holzforschung. 53: 261-266.

Megraw, R.A. 1985. Wood quality factors in loblolly pine: the influence of tree age, position in tree, and cultural practice on wood specific gravity, fiber length, and fibril angle. Atlanta: TAPPI Press. 96 p.

Schimleck, L.R.; Wright, P.J.; Michell, A.J.; Wallis, A.F.A. 1997. Near infrared spectra and chemical compositions of E-globulus and E-nitens plantation woods. Appita Journal. 50: 40-46.

Schultz, T.P.; Burns, D.A. 1990. Rapid secondary analysis of lignocellulose: comparison of near infrared (NIR) and fourier transform infrared (FTIR). Tappi Journal. 73: 209-212.

Wallbacks, L. 1991. Pulp characterization using spectroscopy and multivariate data analysis, PhD Thesis, Dep. Of Organic Chemistry, University of Umea, Umea, Sweden.

Wallbacks, L.; Edlund, U.; Norden, B.; Berglund, I. 1991a. Multivariate characterization of pulp using solid state ^{13}C NMR, FTIR and NIR. Tappi Journal. 74: 201-206.

Wallbacks, L.; Edlund, U.; Norden, B.; Iversen, T. 1991b. Multivariate characterization of pulp. Part 1. Spectroscopic characterization of physical and chemical differences between pulps using ^{13}C CP/MAS NMR, FTIR, NIR and multivariate data analysis. Nordic Pulp Paper Research Journal. 2: 74-80.

Hardwood Thinning and Spacing

Moderator:

GEORGE HOPPER
University of Tennessee

THINNING TO IMPROVE GROWTH AND CONTROL THE CANKER DECAY FUNGUS *INONOTUS HISPIDUS* IN A RED OAK-SWEETGUM STAND IN THE MISSISSIPPI DELTA

James S. Meadows, Theodor D. Leininger, and T. Evan Nebeker[1]

Abstract–Thinning was applied to a 55-year-old, red oak-sweetgum (*Quercus* spp.-*Liquidambar styraciflua* L.) stand in the Delta region of western Mississippi in late summer 1997. The thinning operation was a combination of low thinning and improvement cutting to remove most of the pulpwood-sized trees as well as sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Special emphasis was placed on removing all red oaks infected with *Inonotus hispidus*, a canker decay fungus that causes serious degrade and cull, especially in willow oak (*Quercus phellos* L.) and water oak (*Q. nigra* L.). Prior to thinning, stand density averaged 98 trees and 125 square feet of basal area per acre. Quadratic mean diameter was 15.4 inches, while stocking averaged 102 percent across the study area. Thinning reduced stand density to 32 trees and 59 square feet of basal area per acre, increased quadratic mean diameter to 18.4 inches, and reduced stocking to 47 percent. Thinning also increased the red oak component of the stand from 47 percent of the basal area prior to thinning to 59 percent of the basal area after thinning. There has been little stand-level growth during the first 3 years following the thinning operation. Thinning significantly increased diameter growth of residual trees, especially red oaks, but has not yet produced a significant increase in quadratic mean diameter. Even trees in the dominant crown class experienced increased diameter growth as a result of the thinning operation. Epicormic branching varied widely between species groups. Thinning had no significant effect on epicormic branching in red oaks, but greatly increased the production of new epicormic branches in sweetgum. Three years after thinning, epicormic branches were most numerous on low-vigor sweetgum trees in the lower crown classes. Most importantly, thinning had no effect on the production of epicormic branches along the boles of red oak crop trees.

INTRODUCTION

A combination of thinning and improvement cutting is often used in mixed-species, southern bottomland hardwood forests to not only enhance both stand-level and tree-level growth, but also to improve both species composition and quality of the stand (Meadows 1996). These three characteristics – growth rate, species composition, and quality – are critically important for the profitable management of hardwood stands for high-quality sawtimber production.

Thinning regulates stand density and increases diameter growth of residual trees. In general, diameter growth response increases as the intensity of the thinning increases. However, very heavy thinning may reduce stand density to such a low level that stand-level growth is greatly curtailed even though tree-level growth is greatly enhanced. Stocking simply becomes so low that the stand does not fully realize the potential productivity of the site. Recommended minimum stocking levels necessary to maintain satisfactory stand-level growth have been reported to be 46 to 65 percent in upland oaks (Hilt 1979) and 45 to 60 percent in Allegheny hardwood stands (Lamson and Smith 1988). Thinning in a young water oak plantation to a residual stocking level of 33 percent created a severely understocked condition that will depress stand-level growth for many years (Meadows and Goelz 2001).

Thinning sometimes has adverse effects on the bole quality of residual trees. The production of epicormic branches along the boles of residual trees is often associated with poorly designed thinning operations. However, in stands thinned from below, the proportion of dominant and codominant trees in the residual stand increases as the intensity of the thinning increases. These vigorous, upper-crown-class trees are much less likely to produce epicormic branches than are less-vigorous, lower-crown-class trees (Meadows 1995). Consequently, the production of epicormic branches along the boles of residual trees may actually decrease after well-designed thinnings (Sonderman and Rast 1988).

This combination of thinning and improvement cutting typically used in mixed-species hardwood stands is also designed to improve both species composition and quality of the residual stand (Meadows 1996). In general, the objective is to decrease the proportion of low-value trees and thus to increase the proportion of high-value trees. The emphasis for this component of the cutting operation is on the value, or quality, of the individual trees. Trees that are damaged, diseased, of poor bole quality, or of an undesirable species are removed from the stand, whereas healthy, high-quality trees of desirable species are retained. Improvement cuttings are often performed in stands that contain a high

[1]Principal Silviculturist and Principal Plant Pathologist, USDA Forest Service, Southern Research Station, Stoneville, MS.;Professor, Department of Entomology and Plant Pathology, Mississippi State University, Mississippi State, MS., respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

proportion of diseased trees in an effort to eliminate disease-causing fungi from the stand.

Hardwood stands in the Delta region of Mississippi are often infested with *Inonotus hispidus*, a canker decay fungus that causes the disease commonly known as hispidus canker. The fungus is found most frequently on willow oak and water oak, but also occurs on Nuttall oak (*Quercus nuttallii* Palmer), white oak (*Q. alba* L.), and hickory (*Carya* spp.). Hispidus canker causes serious degrade and cull in infested trees. Damage occurs primarily in the form of heartwood decay, in which the wood behind the canker becomes soft and delignified. The fungus results in the formation of a large, spindle-shaped canker usually at the site of an old branch stub 12 to 15 feet or more up the bole of the infected tree (McCracken 1978). The central part of the canker is sunken and covered with bark. In addition to the degrade caused by the heart rot, presence of the hispidus canker greatly increases the possibility of stem breakage at the site of the canker itself. Improvement cuttings to remove trees with hispidus canker have been successful in reducing spore production and dissemination within the stand, thus minimizing the possibility of the spread of the disease to adjacent trees (McCracken and Toole 1974).

The study reported here is part of a much larger research project that is investigating the relationships between silvicultural practices and insect and disease populations in southern hardwood forests. Specifically, the goals of this larger project are: (1) to better understand and to quantify the effects of stand modification on insect and disease populations in southern hardwood forests, and (2) to use this knowledge to develop pest management recommendations with respect to silvicultural practices in southern hardwood forests.

This paper reports only the silvicultural component of the overall project on one of our study sites. The specific objectives of this individual study are: (1) to determine the effects of thinning on stand growth, development, and yield, and (2) to determine the effects of thinning on individual-tree growth and bole quality. A third objective, not covered in this paper, is to determine the effects of thinning on insect and disease populations, with special emphasis on those pests that lead to degrade and/or mortality.

METHODS

Study Area

The study is located on the Delta National Forest in the Delta region of western Mississippi. The study site is adjacent to Ten Mile Bayou, within the floodplain of the Big Sunflower River, in southeastern Sharkey County. The site is nearly flat and is subject to frequent periodic flooding during the winter and spring months. Floodwaters may remain on the site for several weeks during this period.

Soils across most of the study site belong to the Sharkey series, but smaller areas of Alligator soils are interspersed with the Sharkey soils. Dowling soils also occur in small depressions. All three soils are poorly drained clays that shrink and form wide cracks when dry and expand when wet. These soils formed in fine-textured Mississippi River sediments deposited in slackwater areas of the floodplain. Broadfoot (1976) reported average site indexes of the Sharkey soils to be 92 feet at 50 years for willow oak and 91 feet at 50 years for Nuttall oak. Average site index of the Alligator soils was 88 feet at 50 years for both species. Broadfoot (1976) did not supply similar information for the Dowling soils.

The study area is contained within a 55-year-old red oak-sweetgum stand. Principal red oak species are willow and Nuttall oaks. In addition to sweetgum, other common species include sugarberry (*Celtis laevigata* Willd.), American elm (*Ulmus americana* L.), common persimmon (*Diospyros virginiana* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and honeylocust (*Gleditsia triacanthos* L.).

Plot Design

Plot design was modified from the format for standard plots for silvicultural research, as originally recommended by Marquis and others (1990). Each treatment was uniformly applied across a 4.8-acre rectangular treatment plot that measured 6 by 8 chains (396 by 528 feet). Four, 0.6-acre rectangular measurement plots were established in the center of each treatment plot. Each measurement plot was 2 by 3 chains (132 by 198 feet). A 1-chain buffer strip was established around the four measurement plots. The entire study covered an area of 9.6 acres.

Treatments

Only two treatments were applied to the study area: (1) an unthinned control, and (2) heavy thinning. The thinning operation was a combination of low thinning and improvement cutting. Personnel from the Delta National Forest marked the stand to remove most of the pulpwood-sized trees as well as those sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Special emphasis was placed on removing all red oaks infected with *Inonotus hispidus*.

Four replications of the two treatments were applied in a randomized complete block design to the eight plots (experimental units) in August 1997. Trees were directionally felled by a mechanized feller with a continuously running cutting head. Merchantable products in the form of longwood were removed with rubber-tired skidders.

Measurements

We conducted a preharvest survey to determine species composition and initial stand density on each 0.6-acre measurement plot. We recorded species, diameter at breast height (dbh), crown class, and tree class as defined by Meadows (1996) on all trees greater than or equal to 5.5 inches dbh. The number of epicormic branches on the 16-foot butt log was also recorded on those trees designated as “leave” trees. Log grade, as defined by Rast and others (1973), of the 16-foot butt log and sawtimber merchantable height were recorded on those “leave” trees greater than or equal to 13.5 inches dbh. Crown class, dbh, and the number of epicormic branches on the 16-foot butt log were measured annually for the first 3 years after thinning.

Table 1—Stand conditions and individual-tree diameter growth 3 years after application of two thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability

Treatment	Trees	Mortality	Basal area	Basal area growth	Stocking	Quadratic mean Diameter	Cumulative diameter growth
	(No./acre)	(Pct)	(Sq ft/acre)	(Sq ft/acre)	(Pct)	(In.)	(In.)
Unthinned	99 a	1.0 a	133 a	4 a	108 a	15.7 a	0.23 b
Thinned	30 b	6.2 a	60 b	1 a	48 b	19.0 a	0.60 a

RESULTS AND DISCUSSION

Stand Conditions Prior to Thinning

Prior to thinning, the study area averaged 98 trees and 125 square feet of basal area per acre, with a quadratic mean diameter of 15.4 inches. The average stocking of 102 percent exceeded the level (100 percent) at which thinning is recommended in southern bottomland hardwood stands (Goelz 1995). We found no significant differences among the plots in any of these preharvest characteristics. The stand was fairly dense, but many of the dominant and codominant trees were healthy and exhibited few symptoms of poor vigor. Unfortunately, hispidus canker was observed on approximately 24 percent of the red oaks in the study area.

The stand was clearly dominated by red oak and sweetgum. Red oaks (primarily willow and Nuttall oaks) accounted for about 47 percent of the basal area of the preharvest stand. Red oaks dominated the upper canopy of the stand and had a quadratic mean diameter of 17.2 inches. Sweetgum accounted for about 46 percent of the basal area and occurred in both the upper and middle canopies. Sweetgum quadratic mean diameter was 14.6 inches. Other species, principally sugarberry and American elm, made up the remaining 7 percent of the basal area. These trees were found almost exclusively in the lower canopy of the stand.

Stand Development Following Thinning

Thinning reduced stand density to 32 trees and 59 square feet of basal area per acre, increased quadratic mean diameter to 18.4 inches, and reduced stocking to 47 percent. It removed 67 percent of the trees and 53 percent of the basal area. Average volumes removed during the thinning operation were 3,500 board feet per acre (Doyle scale) of sawtimber and 11 cords per acre of pulpwood. Average dbh of trees removed was 13.5 inches. Thinning produced stand characteristics significantly different from the unthinned control.

This heavy thinning reduced stand density to a level approaching the minimum residual stocking level necessary to maintain satisfactory stand-level growth, as recommended for other hardwood forest types (Hilt 1979, Lamson and Smith 1988). The heavier-than-normal thinning was necessary in this stand because of the desire to remove all of the red oaks infected with hispidus canker. However, even with these additional removals of diseased red oaks, thinning improved species composition of the stand. Thinning increased the red oak component of the stand to 59 percent of the basal area and reduced the sweetgum component to 37 percent of the residual basal area.

During the 3 years following thinning, stand-level growth has been negligible in both the unthinned control and the thinned plots (table 1). In fact, cumulative basal area growth and the increase in stocking percent during the 3-year period following thinning were actually lower in the thinned plots than in the unthinned control, although these differences were not statistically significant. Apparently, this heavy thinning created an understocked stand that will require many years to fully recover from the drastic reduction in stand density.

Diameter Growth

We found significant differences between the thinning treatment and the unthinned control in cumulative diameter growth of individual trees 3 years after treatment (table 1). Thinning increased diameter growth of residual trees by 161 percent when compared to the unthinned control.

Red oaks and sweetgums were similar in their diameter growth response to the thinning treatment (figure 1). Thinning more than doubled diameter growth of both species groups. Cumulative diameter growth of residual red oaks in the thinned plots was 0.64 inches, whereas residual sweetgums in the thinned plots averaged 0.56 inches of

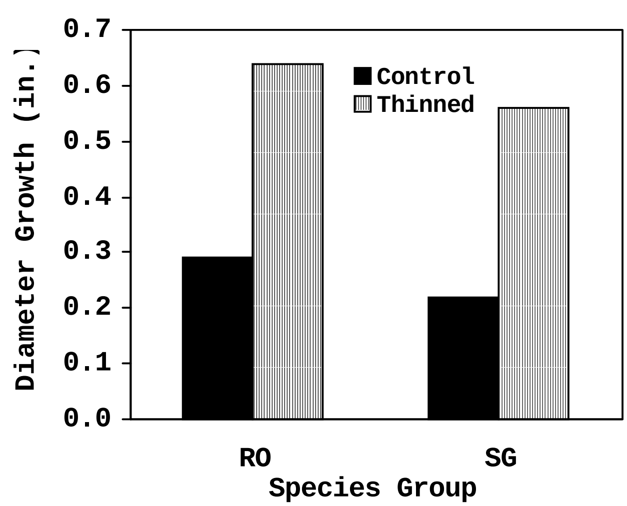


Figure 1–Diameter growth of residual trees, by species group, during the first 3 years after application of two thinning treatments (RO = red oak, SG = sweetgum).

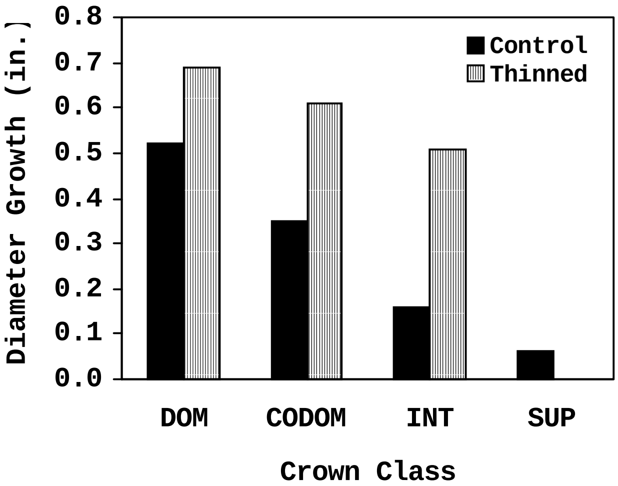


Figure 2–Diameter growth of residual trees, by crown class, during the first 3 years after application of two thinning treatments (DOM = dominant, CODOM = codominant, INT = intermediate, SUP = suppressed).

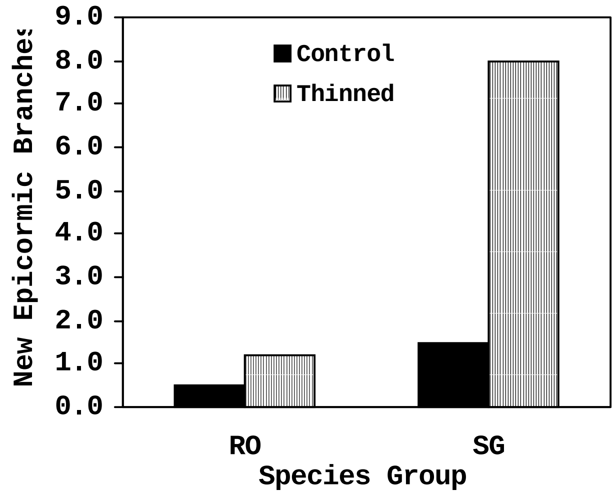


Figure 3–Number of new epicormic branches produced on the butt logs of residual trees, by species group, during the first 3 years after application of two thinning treatments (RO = red oak, SG = sweetgum).

diameter growth over the 3-year period. Cumulative diameter growth of both red oaks and sweetgums in the unthinned control averaged less than 0.30 inches.

Of particular significance in this study is the observation that thinning increased diameter growth of both dominant and codominant trees, when averaged across all species (figure 2). Thinning increased diameter growth of dominant trees by about 33 percent and increased diameter growth of codominant trees by about 74 percent over the unthinned control. Thinning also more than tripled cumulative diameter growth of trees in the intermediate crown class. No comparisons could be made for trees in the suppressed crown class because thinning removed all of the suppressed trees.

It is clear that thinning successfully increased cumulative diameter growth of residual trees 3 years after treatment. Excellent diameter growth responses were observed for both red oak and sweetgum trees in the dominant and codominant crown classes. These trees, especially the red oaks, were classified as crop trees and were considered to be the most desirable trees in the stand for high-quality sawtimber production. The thinning operation, at least through the first 3 years, has been very successful in greatly enhancing the diameter growth of the most valuable trees in the stand.

Epicormic Branching

The production of epicormic branches along the merchantable boles of residual trees can be a serious problem in thinning hardwood stands. These epicormic branches cause defects in the underlying wood and can reduce both log grade and subsequent lumber value. However, well-designed thinnings and proper marking rules can minimize the production of new epicormic branches in most hardwood stands.

In this study, thinning had no significant effects on either the total number or the number of new epicormic branches found on the butt logs of residual trees 3 years after thinning. Residual trees in the thinned plots averaged a total of 6.5 epicormic branches on the butt log; included in this total were 4.1 new epicormic branches produced on the butt log during the 3 years following thinning. On the other hand, trees in the unthinned control averaged 3.8 epicormic branches on the butt log; there were 1.0 new epicormic branches produced on the butt log of these trees during the same 3-year period. Even though residual trees in the thinned plots averaged more total epicormic branches and more new branches on the butt log than trees in the unthinned control, these differences were not statistically significant. Production of new epicormic branches on the butt log varied greatly among individual trees. Some of the high-vigor trees produced no new branches, while many other healthy trees produced only a few. Low-vigor trees, however, generally produced many new epicormic branches.

We found wide variation between the red oaks and sweetgum in the number of new epicormic branches produced on the butt log during the 3 years following thinning (figure 3). Thinning had very little effect on the production of new epicormic branches in red oak, but caused a very large increase in the number of new epicormic branches on the butt logs of residual sweetgum trees 3 years after thinning. Most of the residual red oaks in the thinned stand were high-vigor dominant or codominant trees that are generally less likely to produce epicormic branches than are trees in poor health. Consequently, we found very few new epicormic branches on the butt logs of residual red oaks, even though Meadows (1995) categorized most bottomland red oaks as highly susceptible to epicormic branching. Our observations in this study strongly support the hypothesis proposed by Meadows (1995) that healthy, vigorous trees, even of highly susceptible species, are much less likely to produce epicormic branches than are trees in poor health.

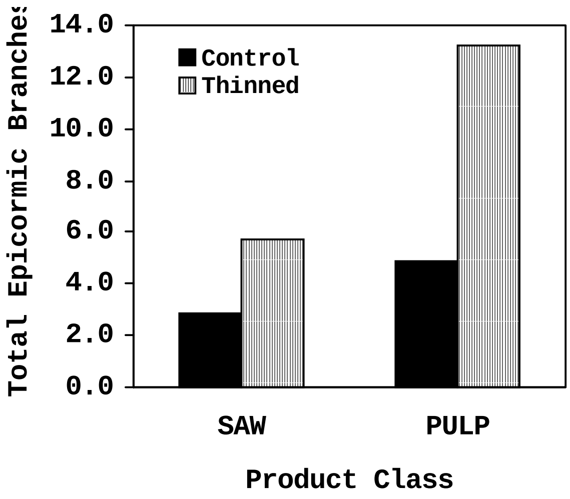


Figure 4–Total number of epicormic branches on the butt logs of residual trees, by product class, 3 years after application of two thinning treatments (SAW = sawtimber, PULP = pulpwood).

When evaluating the effects of thinning on epicormic branching, the most important consideration, however, is the total number of epicormic branches found on the butt logs of the crop trees. These trees are favored during the thinning operation and are most likely to produce high-quality sawtimber. Sawtimber trees in the thinned plots averaged 2.8 more epicormic branches on the butt log than sawtimber trees in the unthinned control, when averaged across all species (figure 4). However, this small difference was not statistically significant. On the other hand, pulpwood trees in the thinned plots had many more epicormic branches on the butt log than pulpwood trees in the unthinned control 3 years after thinning. Most of the pulpwood-sized trees in the residual stand after thinning were relatively low-vigor, lower-crown-class trees that produced many new epicormic branches following the thinning treatment.

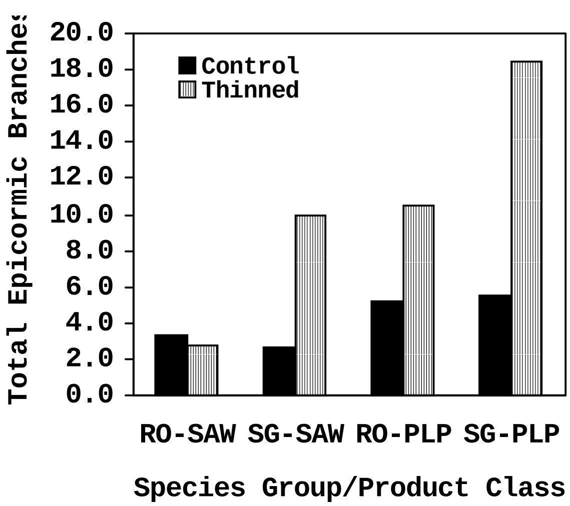


Figure 5–Total number of epicormic branches on the butt logs of residual trees, by species group and product class, 3 years after application of two thinning treatments (RO-SAW = red oak sawtimber, SG-SAW = sweetgum sawtimber, RO-PLP = red oak pulpwood, SG-PLP = sweetgum pulpwood).

Although sawtimber trees in the thinned plots had more epicormic branches on the butt log than sawtimber trees in the unthinned control (figure 4), most of this increase in the number of epicormic branches was found on sawtimber-sized sweetgum trees rather than on sawtimber-sized red oak trees (figure 5). In fact, sweetgum sawtimber trees in the thinned plots averaged 7.3 more epicormic branches on the butt log than sweetgum sawtimber trees in the unthinned control 3 years after treatment. In contrast, red oak sawtimber trees in the thinned plots actually had slightly fewer epicormic branches on the butt log than red oak sawtimber trees in the unthinned control, but this difference was not statistically significant. Consequently, we can conclude that, in this study, thinning to a low level of residual stocking had no effect on the total number of epicormic branches on the butt logs of red oak sawtimber trees, the most valuable trees in the stand.

CONCLUSIONS

1. The thinned stand has been very slow to recover from the thinning operation, with little stand-level growth during the first 3 years.

2. Thinning increased diameter growth of residual trees, especially red oaks, but has not yet resulted in an increase in quadratic mean diameter.

3. Thinning increased diameter growth of codominant trees by 74 percent and diameter growth of dominant trees by 33 percent.

4. Thinning had no effect on epicormic branching in red oak sawtimber trees, but greatly increased the production of new epicormic branches in sweetgum sawtimber trees.

5. Epicormic branches were most numerous on the butt logs of low-vigor, lower-crown-class trees; this was especially true for sweetgum.

ACKNOWLEDGMENTS

We express appreciation to Delta National Forest for providing the study site and for its cooperation in all phases of study installation and measurement. We specifically thank Larry Moore and Ralph Pearce of Delta National Forest for their continuing assistance in this study.

LITERATURE CITED

Broadfoot, Walter M. 1976. Hardwood suitability for and properties of important Midsouth soils. Res. Pap. SO-127. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 84 p.

Goelz, J.C.G. 1995. A stocking guide for southern bottomland hardwoods. Southern Journal of Applied Forestry. 19(3):103-104.

Hilt, Donald E. 1979. Diameter growth of upland oaks after thinning. Res. Pap. NE-437. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.

Lamson, Neil I.; Smith, H. Clay. 1988. Thinning cherry-maple stands in West Virginia: 5-year results. Res. Pap. NE-615. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

Marquis, Dave; Smith, Clay; Lamson, Neil [and others]. 1990. Standard plot layout and data collection procedures for the Stand Establishment and Stand Culture Working Groups, Northeastern Forest Experiment Station. [Warren, PA]: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 55 p.

McCracken, F.I. 1978. Canker-rots in southern hardwoods. Forest Insect & Disease Leaflet 33. Washington, DC: U.S. Department of Agriculture, Forest Service. 4 p.

McCracken, F.I.; Toole, E.R. 1974. Felling infected oaks in natural stands reduces dissemination of *Polyporus hispidus* spores. Phytopathology. 64(2):265-266.

Meadows, James S. 1995. Epicormic branches and lumber grade of bottomland oak. In: Lowery, Glenn; Meyer, Dan, eds. Advances in hardwood utilization: following profitability from the woods through rough dimension: Proceedings of the twenty-third annual hardwood symposium; 1995 May 17-20; Cashiers, NC. [Memphis, TN]: National Hardwood Lumber Association: 19-25.

Meadows, James S. 1996. Thinning guidelines for southern bottomland hardwood forests. In: Flynn, Kathryn M., ed. Proceedings of the southern forested wetlands ecology and management conference; 1996 March 25-27; Clemson, SC. Clemson, SC: Consortium for Research on Southern Forested Wetlands, Clemson University: 98-101.

Meadows, James S.; Goelz, J.C.G. 2001. Fifth-year response to thinning in a water oak plantation in north Louisiana. Southern Journal of Applied Forestry. 25(1):31-39.

Rast, Everette D.; Sonderman, David L.; Gammon, Glenn L. 1973. A guide to hardwood log grading (revised). Gen. Tech. Rep. NE-1. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 31 p.

Sonderman, David L.; Rast, Everette D. 1988. Effect of thinning on mixed-oak stem quality. Res. Pap. NE-618. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

GROWTH OF A 30-YEAR CHERRYBARK OAK PLANTATION 6 YEARS AFTER THINNING

Wayne K. Clatterbuck[1]

Abstract—A 24-year cherrybark oak (*Quercus falcata* var. *pagodifolia*) plantation in the Coastal Plain of west Tennessee was thinned during the winter of 1994-1995. Growth in the plantation was severely stagnated. Trees were planted at a 9 by 9-foot spacing and survival was 69 percent after 24 years after decreasing from 88 percent at age 15. The plantation should have been thinned earlier to avoid the onset of stagnation and the resulting decline in rate of diameter and volume growth. Approximately 50 percent of the stems and 35 percent of the basal area were cut during the row thinning, taking every second row. Results six growing seasons after thinning indicate that the remaining residual trees are increasing in diameter at an annual rate greater than the 9 years prior to the thinning. The plantation volume cut during the thinning operation was replaced by growth on the remaining trees within six years. The volume is accumulating on a fewer number of trees yielding larger diameter trees and increased value over a shorter period of time. A second thinning is projected by age 35. These trends can be used by practitioners as preliminary information on the growth and development of a 30-year-old cherrybark oak plantation before and after thinning.

INTRODUCTION

Thinning is the one operation where merchantable value can be easily increased through regulating stand density and augmenting the diameter growth of residual trees (Hopper and others 1995). Its primary purpose is to salvage trees in immature stands that would normally be lost due to natural stand mortality. Thinning affects merchantable yield by distributing volume growth on fewer, larger trees (Smith 1962).

Although there is a wealth of information about thinning in southern pine stands (Moehring and others 1980), there is a conspicuous absence of thinning information in natural hardwood stands and even less in planted hardwood stands. Meadows and Goelz (2001) recently reviewed the literature on thinning in natural hardwood stands and planted stands.

This research capitalizes on a study for genetic improvement of cherrybark oak. The plantation has been closely monitored and measured periodically for 30 years. This article presents the growth and development of the plantation for the first 24 years before thinning, then the growth results 6 years after thinning. Although this is an unreplicated case study, the 30-year data will give practitioners some long-term information on growth and development of cherrybark oak in plantations before and after thinning.

STUDY AREA

The 1.8-acre cherrybark oak plantation is located on Natchez Trace State Forest (NTSF) in Henderson County, TN, located approximately 10 miles northeast of Lexington, TN near the confluence of Scarce Creek and the Big Sandy River. The forest is managed by the Tennessee Department of Agriculture, Forestry Division (TDA-FD). The plantation is in a second bottom with moderately well-drained, Udifluvent soils (Collins and Iuka series) formed in young alluvium washed from loessal and sandy Coastal Plain materials (Smalley 1991). The area is occasionally flooded during the late winter and early spring by streams or by runoff from higher lying areas, however the duration is only for a few days. Using Smalley's (1991) landscape classification, the study site is landtype #23: narrow moist bottoms. Annual precipitation averages 51 inches, with July through September as the driest months and late winter to early spring as the wettest. Average site index (base age 50) is estimated to be 100-110 feet for cherrybark oak. (Clatterbuck 1987, Smalley 1991).

The NTSF was part of the federal Resettlement Administration purchase of land during the mid-1930's. Before the purchase, the area consisted of marginal and submarginal farms. Most of the cleared land had sustained severe sheet and gully erosion. After the federal government bought the property, many families leased their homes and land and some remained for more than 20 years. By 1959, all families had relocated; their homes and outbuildings were sold, moved or demolished.

The study area is adjacent to Dry Branch, a tributary of Scarce Creek, was cultivated through the mid-1950's and then abandoned. Sediment was deposited from the uplands on this second bottom area until the active erosion was controlled. A variety of soil textures occur because of mixing during transport, active erosion and differential rates of deposition. The field was then maintained in pasture or hay until planting.

The field was planted with 1-0 cherrybark oak in January of 1969 at 9 by 9-foot spacing as part of a tree improvement

[1]Associate Professor, Dept. of Forestry, Wildlife & Fisheries, The University of Tennessee, Knoxville 37901-1071

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

study initiated by the USDA Forest Service, Southern Research Station and TDA-FD to develop a source of genetically improved cherrybark oak for planting in west Tennessee. The planting design was a randomized complete block with 4-tree family plots, 18 families from a Warren County, MS seed source, and 10 replications with 72 trees per replicate.

The planting site was an old field that was heavy in Johnson grass, tall fescue and vetch. Disking was used to prepare the site for planting. Disking and mowing after planting was done at least twice a year for the first four years. Height measurements were taken at age 4 (1973) and age 7 (1976); height and diameter measurements at age 10 (1979), age 15 (1984), and age 24 (1993). The plantation was thinned during the spring of 1994 and the remeasurement was at age 30 (1999).

METHODS

The plantation was measured at age 24 (1993) before thinning. Basal area in 1993 was 103 square feet per acre. Superior phenotypes based on height, diameter and volume were identified. A thinning regime was formulated with the retention of these phenotypes to continue the genetic objectives of the study, namely creation of a cherrybark oak seed production area. The thinning can best be described as a row thinning where every second row was harvested. Selected phenotypes within the harvested rows were retained and one tree on each side of retained phenotypic trees within leave rows was cut. No attempt was made to select inferior trees during the thinning. The goal was to thin approximately 50 percent of the trees resulting in a reduction of 40 percent of the basal area.

RESULTS

Plantation Development after Planting and before Thinning

Very little height growth occurred during the first four growing seasons (table 1), but the rate of height growth increased until the 15-year measurement, then the rate decreased afterward (table 2). Slow initial height growth is characteristic of oak (McGee and Loftis 1986), and may have been further retarded by severe grass and herbaceous competition. The site received at least two mowings per year for the first four growing seasons, which permitted considerable competition from herbaceous vegetation. Grass is perhaps the greatest competitor of planted seedlings (Ford 1999). However, survival rates indicate that cherrybark oak can tolerate such competition in the seedling stage and eventually overtop it, although the growth rate during this period is small. Once established, growth rate increases considerably (table 2) and continues to the 15-year measurement.

Survival was between 88 and 93 percent through age 15, then dropped to 69 percent at age 24. The decrease in survival suggests that trees were exceeding the amount of growing space. The presence of many dead trees scattered throughout the plantation and the presence of epicormic branches along the boles of many trees indicated that the plantation was approaching stagnation. Diameter growth rate was decreasing (tables 1 and 2), another indication that stagnation was taking place. Field observations indicate that adjacent crowns were overlapping and the crowns of many of the subordinate, less vigorous trees were spindly, dying back or dead. From age 15 through age 24 the number of trees per acre decreased from 473 to 372, a mortality rate of 21 percent. Clearly, the plantation should have been thinned at an earlier age to maintain or increase tree growth and development.

Plantation Development after Thinning

Prior to thinning (age 24), the plantation averaged 372 trees per acre (69 percent survival), average basal area of 103 square feet per acre with an average total height of 63 feet and a mean diameter of 6.9 inches. Total stand volume was 2,243 square feet per acre. These data are from all trees regardless of crown class.

Approximately 35 percent of the basal area, 50 percent of the stems and 45 percent of the volume were cut per acre during the thinning. Leaving some of the best phenotypes in the cut rows resulted in more basal area and volume being left than anticipated.

Six years after the thinning, total height continues to increase but at a decreasing rate (table 2). The rate of

Table 1—Changes at different ages, before and after thinning, in mean height, diameter, and volume of trees in a cherrybark oak plantation with associated changes in survival, basal areas and total volume for the plantation

	Individual Tree			Plantation			
Age (yrs)	Mean Height (ft)	Mean Diameter (in)	Mean Volume (cubic ft)	Survival (pct.)	Trees/Acre (#)	Basal Area (sq ft/ac)	Total Volume (cubic ft/ac)
4	2.3	—-	—	93	500	—-	—-
7	9.9	—-	—-	92	495	—-	—-
10	19.3	2.6	—-	91	490	18.1	—-
15	37.3	4.5	1.76	88	473	52.2	832.5
24	61.4	6.9	6.03	69	372	102.6	2,243.2
thinned at age 24							
30	75.6	8.8	12.21	-	190	81	2,139.9

Table 2—Average annual height, diameter and volume growth rates in a 30-year-old cherrybark oak plantation in west Tennessee

Age Interval (yrs)	Height growth rate (ft)	Diameter Growth Rate (in)	Volume Growth Rate (cubic ft)
0 – 4	0.6	—-	—-
5 – 7	2.5	—-	—-
8 – 10	3.1	—-	—-
11 – 15	3.6	0.38	—-
16 – 24	2.7	0.26	0.47
thinned at age 24			
25 – 30	2.4	0.31	1.03

annual diameter growth has increased to 3.1 inches per decade from 2.6 inches before thinning. Diameter growth rates were declining from ages 16-24 because of the onset of stagnation and then began to increase from ages 25-30 after thinning when more growing space was available for crown expansion (table 2).

Since thinning, basal area has increased from 65 to 81 square feet per acre in 6 years or 2.6 square feet per acre annually. If these rates of basal area growth continue, we expect another thinning will be necessary in four to six years.

Average volume per tree doubled in the six years following thinning from an average of 6 to 12 cubic feet per tree, an average annual growth per tree of 1.0 cubic feet per year. Even though approximately 50 percent (1,082 cubic feet per acre) of total volume was harvested during the thinning, total volume of the plantation increased from 1,161 to 2,320 cubic feet per acre or an average volume growth rate of 193 cubic feet per acre per year the following six years. The total amount of volume six years after thinning was essentially the same as the amount of volume before the cut (table 1). The volume is accumulating on a fewer number of trees yielding larger diameter trees and increased value over a shorter period of time.

Trees, particularly oaks, which have been repressed and are under stress have a tendency to develop epicormic branches (Clatterbuck 1993). Although the degree of epicormic branching was not quantitatively assessed in this study, we observed that the number of epicormic branches was greater in the intermediate and suppressed crown classes than the dominant and codominant classes before thinning. Meadows and Goelz (2001) reported similar findings with stressed water oak (*Q. nigra*) plantations. After thinning, epicormic branches remained and were more numerous on trees in subordinate crown classes. On the larger and more vigorous dominant and co-dominant cherrybark oak trees, there were fewer epicormic branches, some of these branches died and were shed and others remained becoming larger in diameter. Without base data for comparison, these trends are not quantifiable, but the thinned plantation does contain high-quality sawtimber trees with few if any epicormic branches.

The diameter distribution of the plantation before thinning resembled a bell-shaped curve with trees being the most abundant in the 8-inch diameter class (figure 1). Six years after thinning where nearly 50 percent of the trees were harvested, the diameter distribution begins to flatten and shift toward the larger diameter-size classes. The greatest number of trees were in the 8 and 10-inch diameter classes. This trend is usually found in even-aged stands of a single species as they develop and mature (Moehring and others 1980, Meadows and Goelz 2001).

DISCUSSION

The cherrybark oak plantation after 24 years was not growing in diameter at an acceptable rate. Diameter growth was 2.6 inches per decade, well below the 3.5 to 4.5 inches per decade that is considered good to excellent growth on productive bottomland sites (Putnam and others 1960). At age 24, the trees were declining because of the competition for growing space resulting in reduced tree growth, increased mortality and declining stand productivity. After thinning, more growing space was available allowing trees to increase in diameter and volume. Six years after thinning, total plantation volume was similar to that when the trees were cut. The volume increase is on fewer trees per acre with larger diameter size and volume per tree. At present rates of diameter and volume growth, the plantation is projected to need thinning again in four to six years.

The first thinning at age 24 probably occurred too late. Natural mortality in the nine years prior to thinning was 22 percent or about 101 trees per acre. The plantation should have been thinned much earlier to avoid growth declines, stress and mortality. The 9 by 9-foot plantation spacing appears desirable for developing merchantable boles and achieving diameters that can be harvested profitably (depending on markets) during the first thinning and achieving plantation basal area and volume growth. Closer

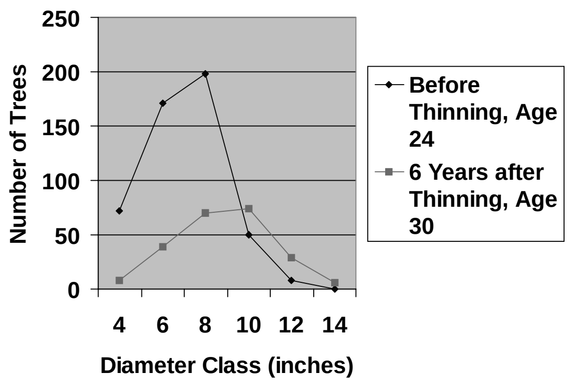


Figure 1—Diameter distribution before thinning and the diameter distribution six years after thinning in a 30-year-old cherrybark oak plantation

spacing will require thinning of smaller diameter material at an earlier age, while wider spacing delays the first thinning, but the tree diameters will be larger.

The tree improvement objective of creating a seed production area from the plantation favored row thinning. The advantage of row thinning is minimal damage to trees within the leave rows. The possible unfavorable effect of row thinning is the removal of good trees and leaving poor trees, creating broad variation between individuals. Many trees in the subordinate crown classes were left within the leave rows. These smaller trees probably deflated the average height, diameter and volume figures reported in this study. Low thinning would have taken most of the subordinate trees and provided a better choice for the leave trees to be retained. A few (eight trees) of the best phenotypic trees were left in the cut rows for future tree improvement studies. The next thinning will probably be a combination of low thinning to remove subordinate trees and a crown or high thinning to remove dominants and codominant trees that are influencing adjacent dominant and codominant trees.

The development of pure plantations generally does not allow the degree of vertical stratification found in mixed species stands. Trees of the same species of similar ages and regeneration origin usually grow and develop at similar rates. Dominance is not expressed quickly since the trees grow at similar rates. In contrast, stratification occurs usually at an early age in mixed species stands (Clatterbuck and Hodges 1988, Oliver 1978). Crown differentiation, especially between different species is readily apparent. The lack of early stratification in single species plantations obscures that these plantations are actively growing and increasing in size. The growth of these stands appears rather gradual. Practitioners should be aware that these pure stands could stagnate after just a few years of intense competition among neighboring trees.

ACKNOWLEDGMENTS

Appreciation is expressed to Russell Cox, staff forester for tree improvement and Phil Hart, forest technician with the Tennessee Department of Agriculture, Forestry Division for the 30-year historical data and measurements, assisting with the thinning operation and maintaining the study area.

REFERENCES

Clatterbuck, W.K. 1987. Height growth and site index curves for cherrybark oak and sweetgum in mixed, even-aged stands on the minor bottoms of central Mississippi. Southern Journal of Applied Forestry. 11(4): 219-222.

Clatterbuck, W.K. 1993. Are overtopped white oak good candidates for management? In: Brissette, J.C., ed. Proc. of the seventh biennial southern silvicultural conference: 1992 November 17-19; Mobile, Al. Gen. Tech. Rep.SO-93. New Orleans, LA: USDA, Forest Service, Southern Forest Experiment Station: 497-500.

Clatterbuck, W.K.; J. D. Hodges. 1988. Development of cherrybark oak and sweetgum in mixed, even-aged bottomland stands in central Mississippi, U.S.A. Canadian Journal of Forest Research. 18(1): 12-18.

Ford, V. 1999. Competition control in plantation oak stands. In: Proceedings from Oak Regeneration Workshop; 1999 April 22; Knoxville, TN. The University of Tennessee, Dept. of Forestry, Wildlife & Fisheries, Knoxville: 27.

Hopper, G.M. (ed.); H. Applegate; D. Dale; R. Winslow. 1995. Forest practice guidelines for Tennessee. Agricultural Extension Service PB 1523, The University of Tennessee, Knoxville. 36 p.

McGee, C.E.; D.L. Loftis. 1986. Planted oaks perform poorly in North Carolina and Tennessee. Northern Journal of Applied Forestry. 3: 114-116.

Meadows, J.S.; J.C.G. Goelz. 2001. Fifth-year response to thinning in a water oak plantation in north Louisiana. Southern Journal of Applied Forestry. 25(1): 31-39.

Moehring, D.M.; J.D. Hodges; T.G. Matney. 1980. Biological assessment of thinning in southern pine plantations. Mississippi State University, Starkville. 171 p.

Oliver, C.D. 1978. The development of northern red oak in a mixed species forest in central New England. Yale University School For. Environ. Stud. Bull., 91. New Haven, CT. 63 p.

Putnam, J.A.; G.M. Furnival; J.S. McKnight. 1960. Management and inventory of southern hardwoods. Agric. Handb. 181. U.S. Department of Agriculture, Washington, DC. 102 p.

Smalley, G.W. 1991. Classification and evaluation of forest sites on the Natchez Trace State Forest, State Resort Park and Wildlife Management Area in west Tennessee. Gen. Tech. Rep. SO-85. New Orleans, LA: USDA Forest Service, Southern Forest Experiment Station. 73 p.

Smith, D.M. 1962. The Practice of Silviculture. Seventh Edition, New York: John Wiley & Sons, Inc. 578 p.

FERTILIZATION AND THINNING IN A 7-YEAR-OLD NATURAL HARDWOOD STAND IN EASTERN NORTH CAROLINA

Leslie P. Newton, Daniel J. Robison, Gerald Hansen, and H. Lee Allen[1]

Abstract—Young even-aged hardwood stands undergo a period of intense competition and self-thinning during the early years of stand development. During this time relatively little growth is accumulated by stems which will persist until rotation age. Silvicultural manipulations which accelerate the rate of stand development, concentrate growth on fewer stems of desirable species and reduce rotation age would be useful options for forest managers. This study reports on an experiment in a 7-year-old stand in northeastern NC, in which growth responses to thinning to 3000 trees per acre and fertilization with N and P were evaluated. Findings indicate that after 3 years, thinning alone did not significantly enhance growth, while fertilization alone or in combination with thinning enhanced growth, and in similar amounts.

INTRODUCTION

Accelerating the growth of naturally regenerated hardwood stands is an important goal of forest managers. Across the southern U.S. many of these stands are even-aged, having regenerated following clearcutting. Through the natural processes of regeneration (including stump and root sprouts, and seedlings), stand consolidation and self-thinning, timber typically reaches merchantable size in 40 to 60 years. Common methods of promoting the growth of these stands take place when the timber is at least pole-sized, often 20 to 30 years old, and stand density has naturally declined to a few thousand stems per acre. Fertilization and thinning in younger stands may accelerate the rate of stand development, concentrating growth on fewer and more valuable stems, and reducing rotation age. These changes could have significant economic advantages.

Studies in natural hardwoods have long demonstrated that thinning can have many positive benefits in production forestry, provided damage to the residual stand and soils are prevented (Gingrich 1971, Heitzman and Nyland 1991). Few studies have reported on stands less than 10 years old. Most reports are from Appalachian uplands. Fertilization in natural stands has been infrequently studied, with reports indicating a variety of stand responses (Dunn and others 1999, Graney and Rogerson 1985, Farmer and others 1970). It is well established that enhancing site resources through fertilization, and reducing inter-tree competition (and herbaceous competition) through density control, and these factors in combination, can enhance productivity, often for many years following treatment (Johnson and others 1997). In the current study we report initial findings from a fertilization and thinning trial in a young North Carolina coastal plain upland hardwood stand.

METHODS

The study site is located on International Paper Company land (formerly a Union Camp Corporation site) in northeastern North Carolina (Northampton County) on a coastal plain mineral flat of somewhat poorly to poorly drained silty clay loam (Lenoir series). These soils can be phosphorus-deficient, with relatively low productivity. The stand consists of naturally regenerated mixed pine-hardwoods, which grew following a commercial clearcut of the prior natural stand in 1990. The current dominant species are sweetgum (*Liquidambar styraciflua* L.), and red maple (*Acer rubrum* L.).

The experimental design was a 2 x 2 factorial (thinning and fertilization as main effects) with three blocks. Treatments were imposed when the stand was 7 years old with a density of approximately 8500 stems per acre. Treatment plots measure 166 ft. x 166 ft., with interior measurement plots of 100 ft. x 100 ft. Within each measurement plot there were 13 circular 154 sq. ft. subplots. Thinning was done in winter 1997 by reducing density to circa 3000 stems per acre with a brushcutter, using spacing and desirable species as a guide. Fertilizer was hand broadcast applied in spring 1998 as 200 lbs. per acre N (in urea and diammonium phosphate [DAP]) and 50 lbs. per acre P (in DAP).

Here we present data on mean tree size (Height and DBH) at age 10 (measured winter 2000/2001), and the 3 year increment between age 7 (measured May 1997) when treatments were applied and age 10. Stand volume, and increment, by treatment are also presented. Volume was estimated by summing subplot standing volumes for each treatment plot, and using an expansion factor to express them on a per acre basis. DBH and height were measured for all stems > 4.5 ft. tall and > 1.5 inches diameter (DBH). Stem volume was calculated as $(DBH^2 * Height) * (0.002)$.

[1]Graduate Student, Professor, Hardwood Research Cooperative, Department of Forestry, North Carolina State University, Raleigh, NC 27695; International Paper Company, Courtland, VA 23837; Professor, Department of Forestry, North Carolina State University, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Mean growth response after 3 years of trees treated at age 7, in a naturally regenerated North Carolina coastal plain upland. Means within a column followed by different letters are significantly different at P = 0.10, by protected LSMeans. "ANOVA" indicates the statistical analysis for each parameter across treatments, and "Fertilization" and "Thin X Fert" indicate the significance of the main effect or treatment interaction for each parameter. Thinning was not a significant main effect.

	- *Measures at Age 10* -		
Treatment (Statistics)	Height (ft.)	DBH (in.)	Volume (cu. ft. per ac.)
Control	22.7 ab	2.43 a	353 a
Thinned	22.0 ab	2.44 a	317 a
Fertilized	23.8 ab	2.52 a	557 b
Thinned + Fertilized	24.6 b	2.82 b	660 c
(ANOVA)	F = 5.99, P = 0.025	F = 6.90, P = 0.018	F = 39.73, P=0.0002
(Fertilization)	P = 0.030	P = 0.070	P = 0.0001
(Thin X Fert)	P = 0.327	P = 0.233	P = 0.056
-	- - - - - - - - - - - *3-Year Cumulative Increment Age 7 to 10* - - - - - - - - - - - - - -		
Control	4.2 a	0.33	266 a
Thinned	4.5 a	0.35	220 a
Fertilized	5.8 b	0.50	479 b
Thinned + Fertilized	6.1 b	0.70	538 b
(ANOVA) 0.0002	F = 8.57, P = 0.011	F = 2.52, P = 0.145	F = 39.56, P =
(Fertilization)	P = 0.010	P = 0.040	P = 0.0001
(Thin X Fert)	P = 0.972	P = 0.434	P = 0.086

Canopy cover was estimated with a spherical densiometer in mid-August 2000. Data were analyzed by the General Linear Model procedure, and when significant differences among treatments were found, means were separated by the LS Means procedure (SAS 1989).

RESULTS AND DISCUSSION

Differences in tree size and cover among the treatments were visually apparent 3 years after thinning and fertilization. Densiometer readings of canopy cover were, control 77 percent, fertilized 86 percent, thinned 56 percent, and thinned + fertilized 83 percent. Ground cover patterns, data not reported here, reflected the inverse of the densiometer readings, and trees were noticeably larger in the treatment plots than the controls. Given the demonstrated positive relationships between leaf area, as approximated by densiometer readings in this case, and productivity (Albaugh and others 1998), we would expect that the treatment plots with high canopy cover would be more productive.

There were no significant differences (P = 0.10) in height, DBH or estimated volume among treatment plots in May 1997 immediately post treatment. Three years after the treatments were applied, mean height, DBH and volume, and 3-year cumulative increments for these measures, differed significantly among treatments (table 1). The interaction between thinning and fertilization was only significant for the volume estimates (table 1). Blocking effects were significant at age 10 for all parameters (P < 0.05). In general, the control and thinned plots did not differ, and had smaller trees than the fertilized and thinned + fertilized plots, which were similar to each other. For all parameters measured, the thinning effect was not significant (P > 0.10), and the fertilization effect was significant (table 1).

The data suggest that height growth was more responsive to the treatments than diameter growth, and that thinning alone did not generate a substantial growth response, whereas fertilization did. Observations of the thinned only plots suggested that thinning in this stand resulted in site resources being made available to competing plants (herbaceous, woody shrubs [notably wax myrtle, *Myrica cerifera*], and stump sprouts of cut trees), without benefit to the residual stand. When thinning was coupled with fertilization, however, the residual stand was apparently able to capture a significant portion of the newly available and added site resources, and exhibit a positive growth response.

These types of interacting biotic and abiotic constraints to growth have been reported, and typically support the idea that thinning alone, when the residual stand is not immediately able to occupy the new space (typical of young stands), does not result in enhanced growth (Graney and Rogerson 1985, Kolb and others 1989, Romagosa and Robison 1999). However, when coupled with weed control and/or fertilization, the response can be substantial (Schuler and Robison, this issue). In the current study, fertilization alone resulted in increased growth for most parameters, and suggests that this low-cost silvicultural intervention may have good operational potential. Although thinning coupled with fertilization did not appreciably increase growth over fertilization alone, the data trends and significant interaction between these treatments (table 1) suggest that over time, the combined effect may be greater than either individual treatment.

The treatments in the current study do not indicate what the effect of thinning + weed control might have been, however other studies suggest that the positive aspects of density reduction can be realized in young stands when weed control is used (Pham 1988, Schuler and Robison, this issue). Further, it cannot be determined which fertilizer element was responsible for the positive effects recorded in this study, nor does this study reveal optimum rates or timing for fertilization. However, the results reported here suggest that substantial productivity gains may be realized in very young stands.

CONCLUSIONS

Fertilization alone and in combination with thinning nearly doubled the 3-year stand volume increment from age 7 to 10 in this study in young natural hardwoods. Thinning alone did not enhance growth in the 3 years post treatment. These findings suggest that early stand silvicultural interventions may substantially accelerate stand development and shorten rotation age, with clear operational potential. If through such practices, species composition and stem quality could also be improved, the benefits to timber production would be enhanced further.

ACKNOWLEDGMENTS

The authors recognize the assistance of Peter Birks, Jim Bridges, David Gadd, Matt Gocke, Pantaleo Munishi and others from the NC State University Hardwood Research Cooperative (HRC) in conducting the field work, Union Camp Corporation (now International Paper Company) for initiating and directly supporting this study, and the support of the HRC membership.

REFERENCES

Albaugh, T.J.; H.L. Allen; P.M. Dougherty; L.W. Kress; J.S. King. 1998. Leaf-area and above- and belowground growth responses of loblolly pine to nutrient and water additions. Forest Science. 44: 317-328.

Dunn, M.A.; K.W. Farrish; J.C. Adams. 1999. Fertilization response in a natural bottomland hardwood stand in north-central Louisiana. Forest Ecology Management. 114: 261-264.

Farmer, R.E.; Jr., G.W. Bengtson; J.W. Curlin. 1970. Response of pine and mixed hardwood stands in the Tennessee Valley to nitrogen and phosphorus fertilization. Forest Science. 16: 130-136.

Gingrich, S.F. 1971. Management of young and intermediate stands of upland hardwoods. Res. Pap. Darby, PA: U.S. Department of Agriculture, Forest Service, NE Experiment Station, Upper NE-195. 26 p.

Graney, D.L.; T.L. Rogerson. 1985. Development of oak, ash and cherry reproduction following thinning and fertilization of upland hardwood stands in the Boston Mountains of Arkansas. In: Prosceedures. Third Southern Silvicultural Research Conference: 171-177.

Heitzman, E.; R.D. Nyland. 1991. Cleaning and early crop-tree release in northern hardwood stands: a review. Northern Journal of Applied Forestry. 8 (3): 111-115.

Johnson, J.E.; J.J. Bollig; R.A. Rathfon. 1997. Growth response of young yellow-poplar to release and fertilization. Southern Journal of Applied Forestry. 21(4): 175-179.

Kolb, T.E.; T.W. Bowersox; L.H. McCormick; K.C. Steiner. 1989. Effects of shade and herbaceous vegetation on first-year germination and growth of direct-seeded northern red oak, white ash, white pine, and yellow-poplar. Gen. Tech. Rep. NC-132: U.S. Department of Agriculture, Forest Service.

Pham, C.H. 1988. Thinning young, natural hardwood regeneration with broadcast herbicide application. In: R.L. Hay and others eds. Proceedings of the Central Hardwood Forest Conference; 1987 February 24-26; Knoxville, TN: 205-215.

Romagosa, M.A.; D.J. Robison. 1999. An evaluation of biological constraints to the early growth of natural hardwood regeneration on North Carolina Piedmont clearcuts. ,In: Waldrop, T.A., ed. Proceedings of the Ninth biennial southern silvicultural research conference; 1997 February 25-27, Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 39-42.

SAS (Statistical Analysis System). 1989. SAS/STAT User's Guide, version 6, 4th ed., Vols. 1 and 2. SAS Institute, Inc., Cary, NC.

EARLY THINNING IN BOTTOMLAND HARDWOODS

Madison P. Howell, III and Lawrence E. Nix[1]

Abstract—A 23-year-old sprout origin stand in the Congaree river bottom near Columbia S.C was commercially thinned in 1994 using standard "Leave Tree", "Trainer Tree", and "Corridor" methods. The stand consisted of 260-325 trees per acre and 28-31 cords per acre. There were 90-140 potential crop trees (30 to 40 percent commercial oaks) of different bottomland species, oaks (*Quercus* spp), sycamore (*Platanus occidentalis*), sweetgum (*Lyquidambar styraciflua*), green ash (*Fraxinus pennsylvania*), red maple (*Acer rubrum*), and sugarberry (*Celtis laevigata*). After 5 years of growth, the effect of thinning on residual crop tree quality was measured by number of epicormic sprouts, degree of logging damage, and vine occurrence. Five years after thinning the 28-year-old stand averages 70 crop trees per acre, 12.4 inches diameter and 2.35 logs commercial height. All thinning methods had twice the number of epicormic sprouts as did the control. Logging damage was the lowest in the trainer tree treatment. Vine occurrence on crop trees was reduced by thinning to half that of the controls (30 versus 60 percent), which is a considerable enhancement in the future quality of crop trees.

INTRODUCTION

Early thinnings in upland and bottomland hardwoods provide the landowner with economic return that would normally be lost to mortality (Gingrich 1971; Kellison and others 1988). These thinnings improve stand quality by changing species composition, selecting quality stems, improving tree spacing, and maintaining crown vigor of desired stems (Carvell 1971).

The thinning of bottomlands favors valuable high quality stems, such as cherry bark (*Quercus pagoda*) and Shumard (*Q. Shumardii*) oaks (Kennedy and Johnson 1984). Some other desirable commercial species to favor with thinnings are green ash, red maple, sweetgum, sugarberry and sycamore. Consideration should be taken to not favor a low quality stem of a high valued species over a high quality stem of a low valued species (Kennedy and Johnson 1984). A crop tree also should be selected based on the vigor and quality of the surrounding stems (Clatterback and others 1987). However, the removal of too many cull trees can leave the stand understocked (Gingrich 1971).

Thinning as early as ages 20-25 years can increase the growth potential and value of bottomland hardwoods on good sites and the increased market for hardwood pulpwood allows productive bottomland sites to be commercially thinned at such early ages (Kellison and others 1988). There is no standard method in thinning hardwoods as it is frequently based on the best judgement of the forester. However, such early thinnings can be marginally commercial if they result in degrade to residual crop trees or require too much time of a professional forester. In early 1993 local consulting foresters approached us concerning the advisability of early thinning in sprout origin bottomland hardwood stands (Personal communication. 1993. Angus Lafaye, Forester, Milliken Forestry, Columbia, SC). The objective of this study was to determine the most effective "standard" commercial thinning method relative to effects of thinning on the future value of residual crop trees in this particular young stand.

METHODS

Study Site

The study site is located in a young bottomland hardwood stand on the Congaree River (a red river) near Columbia, SC. The soil type is a well-drained loamy Typic Udifluvent of the Congaree series. The stand was a 23-year-old sprout origin stand that was KG-blade sheared in 1971. Before thinning the stand consisted of 260-325 trees per acre or 28-31 cords per acre, with 90-140 potential crop trees per acre (30 to 40 percent commercial oaks) of different bottomland species (oaks, sycamore, sweetgum, green ash, red maple, and sugarberry). The criteria for crop trees were that they be a commercial species, have a minimum of one log, of good bole form, minimal epicormic sprouting (less than 3 sprouts in the first log), and be a dominant or co-dominant tree. The stand has a site index (base age 50 years) of 85-95 feet for cherrybark oak.

Experimental Design

The thinning methods were done in a randomized complete block design with four 16-acre blocks containing 4-acre treatments of unthinned control, trainer tree, leave tree, and corridor thinning methods as described by Tinsley and Nix (1998). Each 16 acre block has a main skid trail (20 feet wide) marked down the center with treatments on either side. The control is an uncut area. Analysis of variance for a randomized complete block design was

[1]Forester, Coastal Lumber, Florence, SC; Professor, Department of Forest Resources, Clemson University, Clemson, SC 29634-1003, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

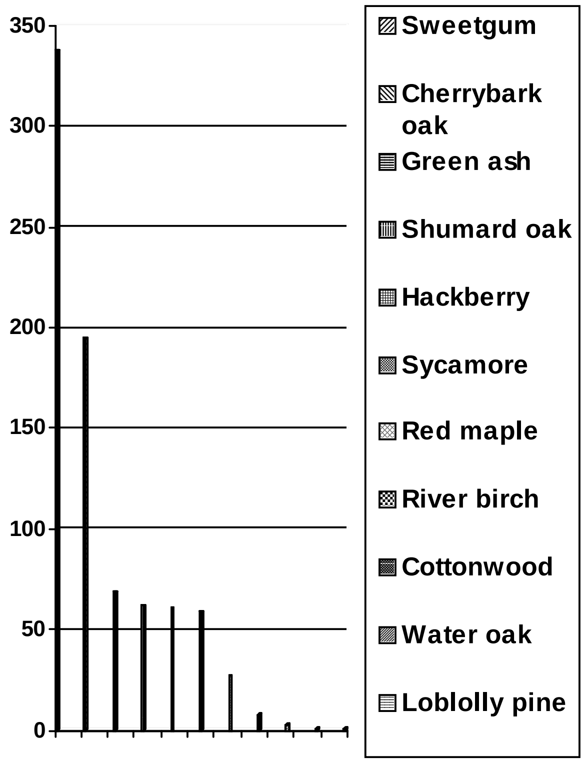


Figure 1— Species prevalence among crop trees (number of the 824 total sampled). Bars in graph from l-r match species list from top to bottom

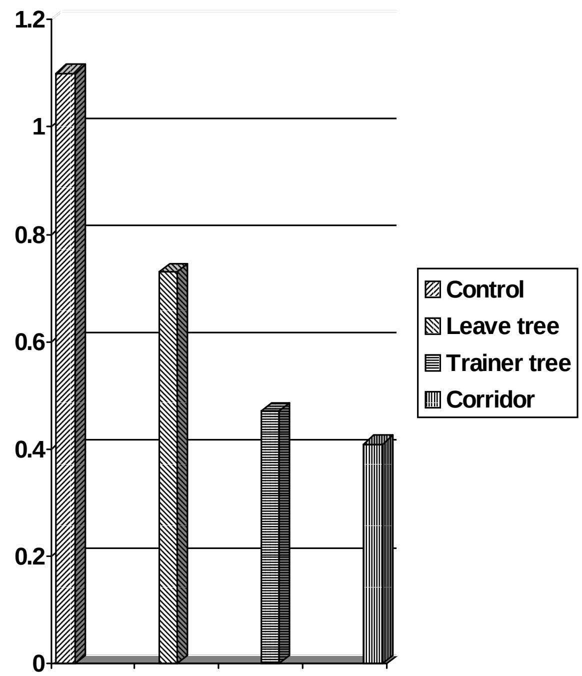


Figure 2— Number of vines on crop trees by thinning method.

performed to test the differences between treatment means (SAS Institute l998). When the treatment means were different Tukey's test at the .05 level of significance was used to test which means were different.

Measurements

A one-acre sampling area was marked in the center of each of the four acre treatment plots, thus, the sample area has a 104.3 feet treatment buffer on all sides. The sample trees were marked before measurements were taken to remove bias from the data. In the corridor treatment the sample crop trees were chosen right up to the edge of the cut strip in order to include the influence of the adjacent open area on future quality. For each crop tree the species, diameter, number of logs, the number of epicormic sprouts (first, second and third log), vine occurrence, vines present in the crown, and logging damage were tallied.

Thinning Methods

All thinning methods were marked to be commercial, at least 10 cords per acre were to be removed (about a 100 trees per acre averaging 8 inches diameter). The trainer tree treatment was designed to leave at least one cull tree near the crop tree to protect it from logging damage and shade out epicormic sprouting on the lower bole. The crop trees were located at 20 by 20 feet spacing (108 trees per acre) in keeping with the 60 percent residual stocking level for upland hardwoods of Gingrich (1971) with about 25 percent more trees per acre added for the more productive bottomland site.

The leave tree method removed all trees except for the crop trees. The same 20 by 20 feet spacing was allowed, but all trees other than crop trees were marked to be cut. If a crop tree was not present at 20 feet, then a reasonable crop tree within a 10 foot radius was left. This method left no protection for the crop trees from logging damage nor shade to suppress epicormic sprouting along the lower bole.

The corridor treatment removed one-third of the volume (about 100 trees per acre) in the cut strip. The forester marked a 20 foot wide cut strip and left a 40 foot wide uncut strip. The cut strips were marked in a 60-degree herringbone pattern to the main skid trail in an attempt to reduce logging damage that results from turning loads. The corridor treatment is an indiscriminate thinning method where crop trees are removed as well as culls.

Vine Control

In most bottomland sites, especially very fertile sites, wild grape vines (*Vitus* spp.) are a problem in the management of high quality crop trees (Smith 1986). Vines can dominate the crown of crop trees causing bad bole form and epicormic sprouting, especially when the vines and crop trees start off as sprouts together. Vines were very prevalent on this site (60 percent of crop trees were infested). Thinning can reduce the number of vines through severing their stems during mechanical harvesting. This is beneficial to the stand. The number and presence of vines in the crowns of crop trees were measured in all treatments.

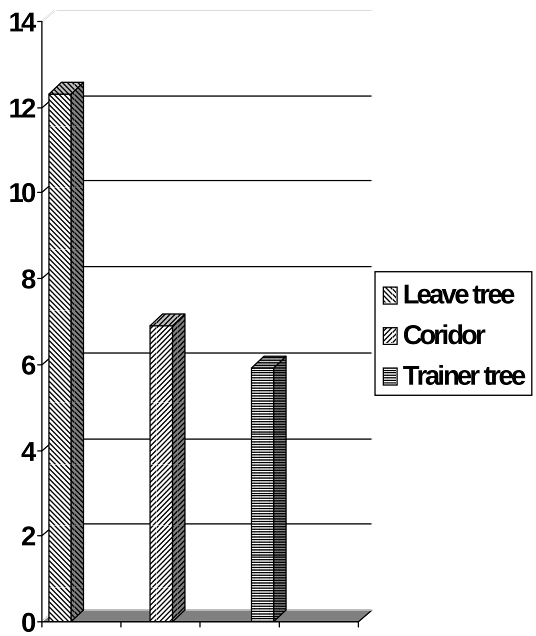


Figure 3— Percent of crop trees damaged from logging by thinning method.

Logging Damage

Thinning operations can be detrimental to the stand because of logging damage. Felling, backing, skidding, and turning with large equipment damage crop trees. This causes a decrease in the number, quality and value of crop trees. Logging damage is reduced through good communication and a well designed harvest plan (Smith 1986). This usually slows down production so an economic incentive (reduction in stumpage value) often is added to reduce careless errors. The objective of each thinning method was explained to the logger and the stumpage value was proportionally decreased to reduce the amount of logging damage that might be caused by haste to make up lost production. However, some logging damage is expected, so each residual crop tree sampled was examined for logging damage.

Epicormic Sprouts

Epicormic sprouts are a source of degrade in hardwood logs. The value of hardwood trees is determined by the grade. The log grade reflects the number and size of clear lumber cuts which can be made from a specific log (Kennedy and Johnson 1984). In opening the canopy the thinning operation may cause epicormic sprouting which will decrease the future financial return. Epicormic sprouts were counted for the first, second and third log of every crop tree sampled.

RESULTS

Residual Crop Trees

The residual stand has an average of 50-90 high quality crop trees per acre depending on the thinning method. Five years after thinning, losses to logging damage and sprout degrade resulted in reducing the leave tree plots to 51.5 crop trees per acre, the corridor method to 81.5, and the trainer tree method to 90.4. This is a drastic reduction in the number of crop trees than that projected before the thinning (at least 100 per acre were to be left). These losses can be partially explained by the premeasurement rejection of crop trees having profuse epicormic sprouting (more than 6 sprouts in the butt log). The remaining crop trees have an average diameter of 12.4 inches and an average height of 2.35 logs. A total of 824 crop trees were sampled and consisted of 41 percent sweetgum, 24 percent cherrybark oak, 8 percent Shumard oak, and 27 percent others (figure 1). An analysis was done to test interactions between treatments and diameter and treatments and species. These interactions were not significant at the 0.05 level.

Vine Occurrence

The number of vines per crop tree was reduced by the thinning treatments. The control trees had nearly twice as many vines as did those of the thinnings (figure 2). Vines were in the crowns of unthinned crop trees nearly two times more often than those thinned (60 versus 30 percent). The control significantly differs from the thinnings which do not differ. The use of heavy machinery in thinnings silviculturally enhanced the future quality of crop trees by reducing the presence of live vines in the crowns.

Logging Damage

Logging damage was kept to a minimum by the following factors: 1) good communications, 2) well-designed harvest plan, and 3) reduced stumpage values charged the logger for less productive methods (Tinsley and Nix 1998). The leave tree thinning damaged 12 percent of the crop trees, the other methods did half of that much damage (figure 3). The leave tree and trainer tree methods differed because the leave tree had no protection from machinery. The trainer tree and corridor thinnings inherently reduce logging damage to residual crop trees.

Epicormic Sprouting

The thinnings caused nearly 3 times more epicormic sprouts on the first log than occurred in the control (figure 4). Similar results occurred on the second and third logs where they existed. The control had significantly fewer sprouts than any of the thinnings. All of the thinnings apparently increased the amount of sunlight in the stand which stimulated epicormic sprouting (Brown and Kormanik 1970). The effects of the thinnings on sprout numbers did not differ. Of the crop tree species Shumard oak had nearly three times the number of sprouts as the other species, a significant difference (figure 5).

Diameter Growth

The average diameter of crop trees in the leave tree thinning was nearly 13 inches, but did not differ from the control. A regression analysis was run to test the correlation

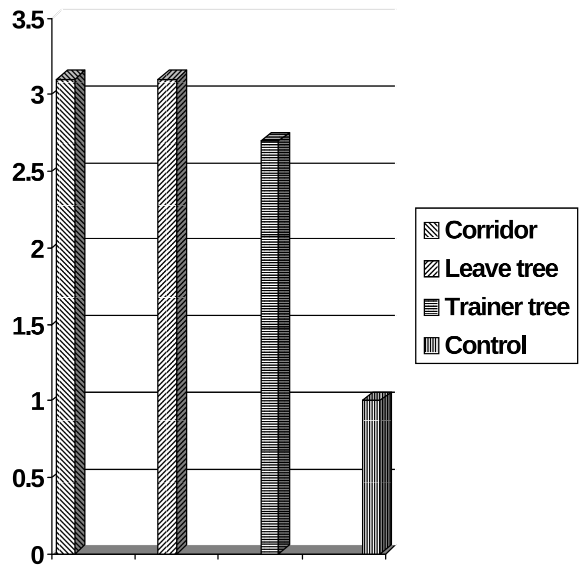


Figure 4— Number of epicormic sprouts on the first log by thinning method.

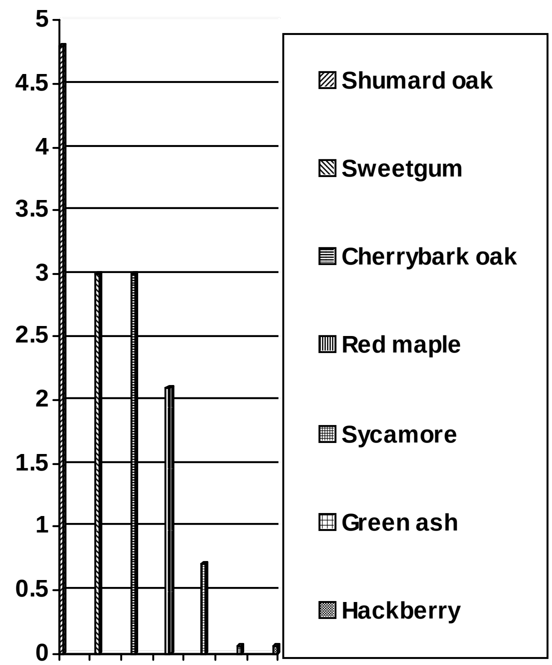


Figure 5— Number of epicormic sprouts on the first log by species.

between diameter and number of epicormic sprouts on the first log. There was a significant negative correlation that showed as the diameter increased the number of epicormic sprouts on the first log decreased, further indication of the negative effect of vigor on epicormic sprouting (Brown and Kormanik 1970).

CONCLUSIONS

All thinning methods met the objective of being a commercial harvest of 10 cords per acre or more and left 100 crop trees per acre. Although the leave tree method was the most productive harvest at 16 cords per acre, five years after thinning it has the greatest reduction of crop trees (over half) due to logging damage and epicormic sprouting. All thinning methods were detrimental to the future stand, producing nearly three times as many epicormic sprouts on the first log as occurred in the control. These sprouts resulted in down grading the number of crop trees left after thinning, reducing the leave tree thinning crop tree numbers by as much as 30 percent.

The control of vines appeared equally as good with the corridor method as the others and it was the most efficient to conduct. However, the corridor method significantly reduced the number of crop trees per acre since a third are removed and another 6 percent were lost to epicormic sprouting. There is no real explanation for the reduced number of vines in the corridor method since machinery activity was confined to the 20 foot wide cut strip. The least amount of logging damage occurred with the trainer tree method, but it was the hardest to mark and least productive for the loggers. The corridor and trainer tree methods proved to be the best thinning methods in this study, but the decision to use either of these methods should be based on careful consideration of the conditions of the existing stand.

If the stand has adequate desirable high quality stems (140 or more per acre) then the corridor method can be used if a target of at least 100 residual crop trees per acre averaging 12 inches diameter is desired. If the existing stand has at least 110 crop trees per acre, then the trainer tree method can be used. Because of the 12 percent logging damage to crop trees, and the 30 percent reduction in crop trees for epicormic sprouting, the leave tree thinning method should not be used in stands such as in this study unless at least 140 desirable crop trees can be marked to be left per acre. The effects of thinning on crop tree quality and growth in these study plots will be monitored again in the future.

ACKNOWLEDGMENTS

The authors would like to thank Frank McLeod, Consulting Forester of Shaw, McLeod, Belser, and Hurlburt, Sumter, SC for providing valuable time and technical assistance. Special appreciation is expressed to the owner, Robert Boardman, and the Boardman Carton Trusts, for providing an excellent area to conduct the study. Thanks is also in order for Marion Burnside and Millaree Hunting Club for providing us with wonderful southern hospitality and

lodging. John Hane and Roddy Cooper, former graduate assistants at Clemson University, are especially thanked for their enthusiasm and hard work on the project.

REFERENCES

Brown, C.L.; Kormanik, P.P. 1970. The influence of stand disturbance on epicormic branching. In: Silviculture and Management of Southern Hardwoods, 19th Annual Forestry Symposium. Baton Rouge, LA: LSU: 103-112.

Carvell, Kenneth L. 1971. Silvicultural aspects of intermediate cuttings. In: Proceedings, Oak Symposium; 1971 August 16-20; Morgantown, West Virginia. Upeer Darby, PA: U.S. Department of Agriculture, Forest Service, NE Forest Experiment Station: 60-64.

Clatterbuck, W.K.; Olliver, C.D.; Burkhardt, E.C. 1987. The silvicultural potential of mixed stands of cherrybark oak and American sycamore: spacing is the key. Southern Journal of Applied Forestry 11(3): 158-161.

Gingrich, S.F. 1971. Stocking, growth, and yield of oaks stands. In: Proceedings, Oak Symposium; 1971 August 16-20; Morgantown, West Virginia. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, NE Forest Experiment Station: 65-73..

Kellison, R.C.; Martin, J.P.; Hansen, G.D.; Lea, R. 1988. Regenerating and managing natural stands of bottomland hardwoods. APA 88-A-6. Bottomland Hardwood Management Taskforce, Southeastern Technical Division, American Pulpwood Association, Inc. 26 p.

Kennedy, H.E.; Johnson, R.L. 1984. Silvicultural alternatives in bottomland hardwoods and their impact on stand quality. In: Proceedings, 14th Annual Southern Forest Economics Workshop; 1984 March 13-15; Memphis, TN. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 6-18.

SAS Institute 1999. SAS User's Guide: Statistical Version 6. Carey, NC. 484 p.

Smith, D.M. 1986. The Practice of Silviculture. New York: John Wiley & Sons, Inc. 525 p.

Tinsley, M.B.; Nix, L.E. 1998. Early thinnings in a young, sprout-origin, bottomland hardwood stand in South Carolina. In: Proceedings, Ninth Biennial Southern Silvicultural Research Conference; 1997 February 25-27; Clemson, SC. Ashville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 170-174.

FOURTH-YEAR EFFECTS OF THINNING ON GROWTH AND EPICORMIC BRANCHING IN A RED OAK-SWEETGUM STAND ON A MINOR STREAMBOTTOM SITE IN WEST-CENTRAL ALABAMA

James S. Meadows and J.C.G. Goelz[1]

Abstract–Four thinning treatments were applied to a 60-year-old, red oak-sweetgum (*Quercus* spp.-*Liquidambar styraciflua* L.) stand on a minor streambottom site in west-central Alabama in late summer 1994: (1) unthinned control; (2) light thinning to 70-75 percent residual stocking; (3) heavy thinning to 50-55 percent residual stocking; and (4) B-line thinning to desirable residual stocking for bottomland hardwoods, as recommended by Putnam and others (1960). The thinning operation consisted of a combination of low thinning and improvement cutting to remove most of the pulpwood-sized trees as well as sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Prior to thinning, stand density averaged 196 trees and 121 square feet of basal area per acre. Average stand diameter was 10.7 inches, while stocking averaged 107 percent across the 24-acre study area. Light thinning reduced stand density to 83 trees and 82 square feet of basal area per acre, increased average stand diameter to 13.5 inches, and reduced stocking to 69 percent. Heavy thinning reduced stand density to 49 trees and 64 square feet of basal area per acre, increased average stand diameter to 15.5 inches, and reduced stocking to 52 percent. Putnam's B-line thinning reduced stand density to 65 trees and 86 square feet of basal area per acre, increased average stand diameter to 15.6 inches, and reduced stocking to 70 percent. Only small increases in stand-level basal area and average stand diameter were observed in the thinned areas 4 years after thinning. Thinning significantly increased diameter growth of residual trees, across all species, but there were only slight differences among the three levels of thinning. These increases in diameter growth were most pronounced among red oaks. Thinning produced only small increases in the number of new epicormic branches on the butt logs of residual trees, averaged across all species. Epicormic branching varied widely across both species and crown classes. Thinning had little effect on epicormic branching in red oaks, but greatly increased the production of new epicormic branches in sweetgum. Heavy thinning appears to have produced the best combination of stand-level growth and individual-tree diameter growth, with minimal increases in epicormic branching, especially among red oak crop trees.

INTRODUCTION

Profitable management of hardwood stands for sawtimber production depends not only on maintenance of satisfactory rates of growth, but also on successful development and maintenance of high-quality logs. In general, a combination of thinning and improvement cutting can be used in most mixed-species bottomland hardwood forests to: (1) enhance growth of individual residual trees, (2) improve stand-level growth, (3) maintain and improve bole quality of residual trees, and (4) improve species composition of the stand (Meadows 1996).

Thinning regulates stand density and increases diameter growth of residual trees, as has been reported for several hardwood forest types, such as upland oaks in the Midwest (Hilt 1979, Sonderman 1984b), cherry-maple (*Prunus* spp.-*Acer* spp.) in the Allegheny Mountains (Lamson 1985, Lamson and Smith 1988), and mixed Appalachian hardwoods (Lamson and others 1990). In general, the heavier the thinning, the greater the diameter growth response of individual trees. However, very heavy thinning may reduce residual stand density to the point where stand-level basal area growth and volume growth are greatly diminished, even though diameter growth and volume growth of individual residual trees are greatly enhanced. In very heavily thinned stands, site occupancy may be less than optimum because the stand does not fully realize the potential productivity of the site. Recommended minimum residual stocking levels necessary to maintain satisfactory stand-level growth and to ensure full occupancy of the site are 46 to 65 percent in upland oaks (Hilt 1979) and 45 to 60 percent in cherry-maple stands (Lamson and Smith 1988). Residual stand density equivalent to 52 percent stocking in a young water oak (*Quercus nigra* L.) plantation appeared to be sufficient to promote adequate basal area growth following thinning, whereas a residual stocking level of 33 percent created a severely understocked stand that will be unable to fully occupy the site for many years to come (Meadows and Goelz 2001).

[1]Principal Silviculturist, USDA Forest Service, Southern Research Station, Stoneville, MS; Principal Forest Biometrician, USDA Forest Service, Southern Research Station, Pineville, LA, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Degradation of bole quality of residual trees is also sometimes associated with increased thinning intensity. For example, the number and size of both living and dead limbs on the boles of residual upland oak trees increased significantly as residual stocking decreased (Sonderman 1984a). On the other hand, Sonderman and Rast (1988) found that the production of epicormic branches on residual oak stems decreased with increasing thinning intensity. In stands thinned from below, the proportion of dominant and codominant trees in the residual stand increases as the intensity of thinning increases. These vigorous, upper-crown-class trees are less likely to produce epicormic branches than are less-vigorous, lower-crown-class trees (Meadows 1995). Consequently, a well-designed thinning should improve average bole quality throughout the residual stand. In many stands, however, there may be a trade-off between improved diameter growth and the potential for adverse effects on bole quality of residual trees, as thinning intensity increases and residual stand density decreases.

A combination of thinning and improvement cutting can also be used to improve species composition of mixed-species hardwood stands (Meadows 1996). In general, the goal is to decrease the proportion of low-value species and thus increase the proportion of high-value species. Although most important at the time of the first thinning, improvement of species composition should be a major consideration whenever a partial cutting is performed in mixed-species hardwood stands.

These four components of thinning, increased diameter and volume growth of individual trees, increased stand-level basal area and volume growth, enhanced bole quality, and improved species composition, are critically important for the profitable management of hardwood stands for high-quality sawtimber production. Ideally, thinning regimes should be designed to optimize the value of the stand, as determined by these four components. However, because maximization of all four components is not possible, some trade-offs in expected benefits must be accepted.

Research on thinning in southern bottomland hardwood forests is lacking. Existing guidelines, such as those recommended by McKnight (1958), Johnson (1981), Meadows (1996), and Goelz and Meadows (1997), are too general and are based more on experience and observation rather than on actual research results. Successful management of southern bottomland hardwood stands for high-quality sawtimber production requires quantitative thinning guidelines that include recommendations on: (1) timing of the first and subsequent thinnings, (2) intensity of thinning, and (3) marking rules designed to optimize stand value throughout the rotation.

To address this need for quantitative thinning guidelines, we are establishing a series of thinning studies in red oak-sweetgum stands on minor streambottom sites across the South. All studies in the series use the same study design, treatments, and methods. The study reported here is the first in the series. All individual studies within the series are designed to determine the effects of several levels of thinning on: (1) stand-level growth, development, and yield, and (2) growth and bole quality of individual trees. Results from the entire series of 10-12 studies will be combined to: (1) develop practical guidelines for the intermediate management of southern bottomland hardwood stands, (2) evaluate the applicability of various levels of recommended residual stocking across a wide variety of site and stand conditions, and (3) develop a growth and yield model for managed stands of southern bottomland hardwoods.

METHODS

Study Area

The study is located within the floodplain of the Tombigbee River in northeastern Sumter County near the community of Warsaw in west-central Alabama. The land is owned by Gulf States Paper Corporation. The site is subject to periodic flooding during the winter and spring months, but floodwaters generally recede within a few days.

Soils across most of the study site belong to the Ochlockonee series, but there are small areas of Falaya soils in the lower areas. The Ochlockonee soils are well-drained, but the Falaya soils are somewhat poorly drained. Infiltration and permeability rates are moderate to rapid across the site. Both soils have moderate-to-high natural fertility and high available water capacity. Texture in the upper soil horizon across the study area is silt loam to fine sandy loam. Soil pH is very strongly acid and ranges from 4.5 to 5.5 across the site. Broadfoot (1976) reported average site indexes of the Ochlockonee soils to be 110 feet at 50 years for water oak and 112 feet at 50 years for sweetgum, and estimated site index for cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.) to range from 100 to 120 feet at 50 years. The Falaya soils are only slightly less productive. Site indexes are reported to average 101 feet at 50 years for water oak, 111 feet at 50 years for sweetgum, and 108 feet at 50 years for cherrybark oak (Broadfoot 1976).

The study area is located within a 74-acre stand composed primarily of red oak, sweetgum, and hickory (*Carya* spp.). Principal red oak species are cherrybark and water oaks, with scattered trees of willow oak (*Quercus phellos* L.), southern red oak (*Q. falcata* Michx.), and Shumard oak (*Q. shumardii* Buckl.). White oak species include white oak (*Q. alba* L.), overcup oak (*Q. lyrata* Walt.), and swamp chestnut oak (*Q. michauxii* Nutt.). The stand was about 60 years old at the time of study installation. There was no evidence of previous harvesting activity in the stand. Based on an inventory by Company personnel in 1993, sawtimber volume averaged 6,520 board feet per acre (Doyle scale), of which 81 percent was red oak, and pulpwood volume averaged 12.5 cords per acre (Personal communication. Sam Hopkins. 1993. Research Manager, Gulf States Paper Corporation, P.O. Box 48999, Tuscaloosa, AL 35404).

Plot Design

Plot design followed the recommendations for standard plots for silvicultural research, set forth by the U.S. Forest Service's Northeastern Forest Experiment Station (Marquis and others 1990). Each individual treatment was uniformly applied across a 2.0-acre, rectangular treatment plot that measured 4 by 5 chains (264 by 330 feet). One, 0.6-acre, rectangular measurement plot was established in the center of each treatment plot. Each measurement plot was 2 by 3 chains (132 by 198 feet), providing a 1-chain buffer around each. The entire study covered an area of 24 acres.

Treatments

Treatments were defined as four levels of residual stocking, based on a stocking guide developed by Goelz (1995) for southern bottomland hardwoods: (1) an unthinned control, (2) light thinning to 70 to 75 percent residual stocking, (3) heavy thinning to 50 to 55 percent residual stocking, and (4) B-line thinning to desirable residual stocking following partial cutting in well-managed, even-aged southern bottomland hardwoods, as recommended by Putnam and others (1960).

A combination of low thinning and improvement cutting was used to remove most of the pulpwood-sized trees as well as sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Hardwood tree classes, as originally defined by Putnam and others (1960) and modified by Meadows (1996), formed the cutting priority for each treatment. Trees were removed from the cutting stock and cull stock classes first and then from the reserve growing stock class, when necessary, until the target residual stocking was met.

Three replications of the four treatments were applied in a randomized complete block design to the 12 treatment plots (experimental units) in September 1994. A contract logging crew directionally felled all trees with a mechanized feller and used rubber-tired skidders to remove the merchantable products in the form of longwood. Most of the material cut was utilized as pulpwood.

Measurements

We conducted a preharvest survey to determine species composition and initial stand density on each 0.6-acre measurement plot. We recorded species, diameter at breast height (dbh), crown class, and tree class on all trees greater than or equal to 3.5 inches dbh. Based on hardwood tree classes, we marked the stand for thinning to the target residual stocking prescribed for each treatment. The length and grade of all sawlogs, as defined by Rast and others (1973), and the number of epicormic branches on each 16-foot log section were recorded on those trees designated as “leave” trees. We also measured sawtimber merchantable height, height to the base of the live crown, and total height on a subsample of “leave” trees. Crown class, dbh, and the number of epicormic branches on each 16-foot log section were measured annually for the first 4 years after thinning. Previous results were reported by Meadows and Goelz (1998, 1999).

RESULTS AND DISCUSSION

Stand Conditions Prior to Thinning

Prior to thinning, the stand averaged 196 trees and 121 square feet of basal area per acre, with a quadratic mean diameter of 10.7 inches. The average stocking of 107 percent exceeded the level (100 percent) at which thinning is recommended in southern bottomland hardwood stands (Goelz 1995). We found no significant differences among treatment plots in any preharvest characteristics. Although the stand was dense, most of the upper-crown-class trees were healthy and exhibited few symptoms of poor vigor, such as crown deterioration, loss of dominance, or the presence of numerous epicormic branches along the boles. Little sunlight reached the forest floor, except in small gaps created by the death of scattered trees throughout the stand. The stand needed thinning but was not stressed to the point of stagnation at the time of study installation.

This even-aged, mixed-species stand was dominated by red oak, hickory, and sweetgum. Red oaks (primarily cherrybark and water oaks, but with lesser numbers of willow, southern red, and Shumard oaks) accounted for about 45 percent of the basal area of the preharvest stand. Red oaks dominated the upper canopy and had a quadratic mean diameter of 16.1 inches. Mockernut hickory [*Carya tomentosa* (Poir.) Nutt.] and shagbark hickory [*C. ovata* (Mill.) K. Koch] together accounted for about 25 percent of the basal area. Hickories were found primarily in the mid-canopy, but scattered individuals occurred in the upper canopy. Sweetgum made up about 12 percent of the basal area and occurred primarily as lower-crown-class trees. Other species scattered throughout the stand included white, overcup, and swamp chestnut oaks, green ash (*Fraxinus pennsylvanica* Marsh.), American elm (*Ulmus americana* L.), and winged elm (*U. alata* Michx.). Along with small hickories and sweetgum, American hornbeam (*Carpinus caroliniana* Walt.), red mulberry (*Morus rubra* L.), black tupelo (*Nyssa sylvatica* Marsh.), and various maples dominated the understory.

Table 1—Stand conditions and individual-tree diameter growth 4 years after application of four thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability

Treatment	Trees	Mortality	Basal area	Basal area growth	Stocking	Quadratic mean diameter	Cumulative diameter growth
	No./acre	Pct	Sq ft/acre	Sq ft/acre	Pct	In.	In.
Unthinned	169 a	8.2 a	121 a	4 ab	105 a	11.4 b	0.33 c
Light thinning	78 b	6.0 a	85 bc	3 b	70 b	14.3 ab	0.58 b
Heavy thinning	49 c	0.0 a	70 c	6 a	57 c	16.6 a	0.69 ab
B-line thinning	59 bc	9.2 a	91 b	5 ab	74 b	16.9 a	0.78 a

Table 2—Total number and number of new epicormic branches on the butt logs and on upper logs of residual trees 4 years after application of four thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability

Treatment	---------------*Butt logs*---------------		--------------*Upper logs*-------------	
	Total epicormic branches	New epicormic branches	Total epicormic branches	New epicormic branches
Unthinned	6.7 a	1.1 b	15.1 a	4.0 a
Light thinning	4.2 a	3.1 a	16.5 a	7.8 a
Heavy thinning	3.8 a	2.7 a	13.8 a	6.5 a
B-line thinning	4.8 a	3.1 a	14.6 a	7.3 a

Stand Development Following Thinning

Light thinning reduced stand density to 83 trees and 82 square feet of basal area per acre, increased quadratic mean diameter to 13.5 inches, and reduced stocking to 69 percent. It removed 62 percent of the trees and 31 percent of the basal area. Heavy thinning reduced density to 49 trees and 64 square feet of basal area per acre, increased quadratic mean diameter to 15.5 inches, and reduced stocking to 52 percent. It removed 73 percent of the trees and 43 percent of the basal area. B-line thinning reduced stand density to 65 trees and 86 square feet of basal area per acre, increased quadratic mean diameter to 15.6 inches, and reduced stocking to 70 percent. It removed 68 percent of the trees and 37 percent of the basal area. All thinning treatments produced stand characteristics significantly different from the unthinned control. Average dbh of trees removed during the logging operation ranged from 7.1 inches in the light thinning treatment to 8.3 inches in the B-line thinning treatment. Overall average dbh of trees removed was 8.0 inches.

Thinning also improved species composition of the residual stand. All thinning treatments increased the proportion of red oak and decreased the proportions of both sweetgum and hickory within the residual stand. Most of the sweetgum and hickory removed from the stand were lower-crown-class trees and were utilized as pulpwood.

During the 4 years following thinning, we observed a small amount of mortality in all of the plots, except those subjected to heavy thinning (table 1). Most of the mortality occurred as a result of windthrow. These decreases in the number of trees per acre during the 4 years following thinning were not significantly different among treatments.

Stand-level basal area growth and increases in stocking and quadratic mean diameter indicate that the stand may be recovering faster from heavy thinning and B-line thinning than from light thinning (table 1). We measured only small increases in stand-level basal area in the lightly thinned and unthinned stands during the 4 years following thinning. However, larger increases in basal area were found as a result of heavy thinning and B-line thinning. In fact, cumulative basal area growth in the heavily thinned stand was significantly greater than cumulative basal area growth in the lightly thinned stand, such that there is no longer a statistical difference between these two treatments in total basal area 4 years after thinning, a situation not found in earlier measurements (Meadows and Goelz 1998). A similar trend was observed for changes in stocking percent among the four treatments (table 1), but these increases were not statistically significant 4 years after thinning. All treatments also produced increases in quadratic mean diameter (table 1), with heavy thinning and B-line thinning again resulting in the largest increases (1.1 inches and 1.3 inches, respectively), as compared to 0.6 inches and 0.8 inches in the unthinned and lightly thinned stands, respectively. Although these results follow the same trend as that observed for stand-level basal area growth, these increases in quadratic mean diameter did not differ significantly among the four treatments.

Diameter Growth

We found significant differences between all three of the thinning treatments and the unthinned control in cumulative diameter growth of individual trees 4 years after treatment (table 1). Depending upon treatment, thinning increased diameter growth of residual trees by 76 to 136 percent when compared to the unthinned control. For the first time since study installation, we also detected differences among the three levels of thinning. Cumulative diameter growth of residual trees 4 years following B-line thinning was

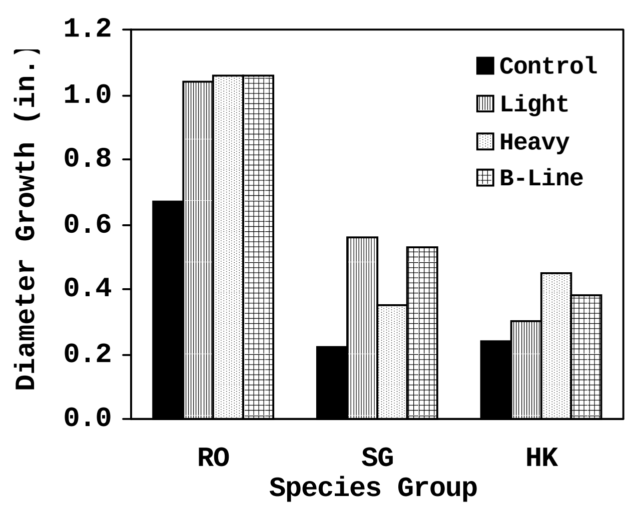


Figure 1–Diameter growth of residual trees, by species group, during the first 4 years after application of four thinning treatments (RO=red oak, SG=sweetgum, HK=hickory).

significantly greater than diameter growth of residual trees following light thinning. As the study continues, we expect to find even greater differences among the three levels of thinning.

Individual species groups varied significantly in their diameter growth response to the four treatments (figure 1). All three levels of thinning increased cumulative diameter growth of residual red oaks by about 55 percent after 4 years (a little more than 1.0 inches as compared to about 0.7 inches for red oaks in the unthinned control). All three thinning treatments also greatly increased cumulative diameter growth of residual sweetgum trees, but response was less than that observed among red oaks. Cumulative diameter growth of hickory was relatively poor, but the largest increases occurred in response to heavy thinning and B-line thinning.

None of the three levels of thinning significantly affected cumulative diameter growth of dominant trees, when averaged across all species, but heavy thinning and B-line thinning increased cumulative diameter growth of codominant trees by about 33 percent over the unthinned control (figure 2). Both the heavy and B-line thinning treatments also nearly doubled cumulative diameter growth of trees in the intermediate crown class. Light thinning failed to produce significant increases in cumulative diameter growth of trees in any of these three crown classes. Cumulative diameter growth response of suppressed trees 4 years after thinning was erratic across treatments primarily because thinning removed most of these small inferior trees.

It is clear that all three levels of thinning successfully increased cumulative diameter growth of residual trees 4 years after thinning. The largest increases in diameter growth as a result of thinning were observed among red oaks in the codominant crown class. In most situations, codominant red oaks were classified as crop trees and were considered to be the most desirable trees for high-quality sawtimber production. Our thinning guidelines were designed to favor these trees and, at least so far, we appear to have been successful in enhancing the diameter growth of the most desirable trees in the stand.

Epicormic Branching

The production of epicormic branches along the merchantable boles of residual trees can be a serious problem in thinning hardwood stands. These epicormic branches cause defects in the underlying wood and can reduce both log grade and subsequent lumber value.

Because we removed most of the trees of poor bole quality during the thinning operation, residual trees in the thinned plots, on average, had fewer epicormic branches on the butt log 4 years after thinning than did trees in the unthinned control, but these differences were not statistically significant (table 2). However, all levels of thinning significantly increased the production of new epicormic branches on the butt log, even though trees in all thinning treatments averaged only about three new branches during the first 4 years after thinning. Epicormic branching on upper logs was uniformly high, regardless of treatment (table 2). Production of new epicormic branches varied greatly among individual trees. Some of the high-vigor trees produced no new branches, while many others produced only a few. Low-vigor trees, on the other hand, generally produced many new epicormic branches. Production of new epicormic branches, especially on the butt log, seems to be a delayed consequence of thinning. Meadows and Goelz (1998) reported that trees in all treatments averaged less than one new epicormic branch during the first year after treatment in this study. Our subsequent observations indicate that the majority of new epicormic branches were produced during the second year and that production of new branches during the third and fourth years was negligible. However, most new epicormic branches produced during the first 3 years survived through the fourth year.

Wide variation was found among species groups in the number of new epicormic branches produced on the butt log during the 4 years following thinning (figure 3). For

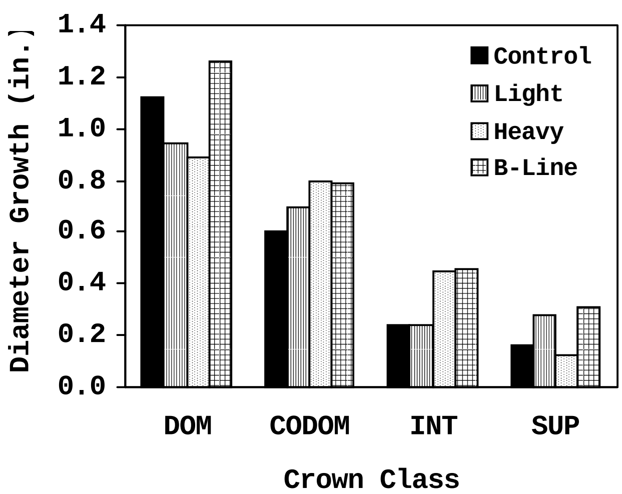


Figure 2–Diameter growth of residual trees, by crown class, during the first 4 years after application of four thinning treatments (DOM=dominant, CODOM=codominant, INT=intermediate, SUP=suppressed).

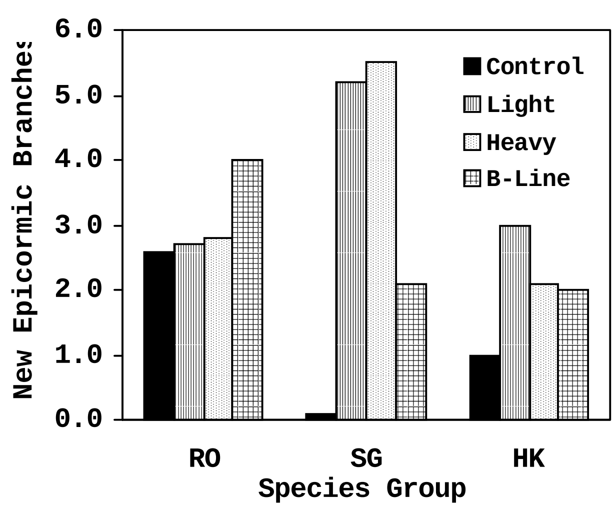


Figure 3–Number of new epicormic branches produced on the butt logs of residual trees, by species group, during the first 4 years after application of four thinning treatments (RO=red oak, SG=sweetgum, HK=hickory).

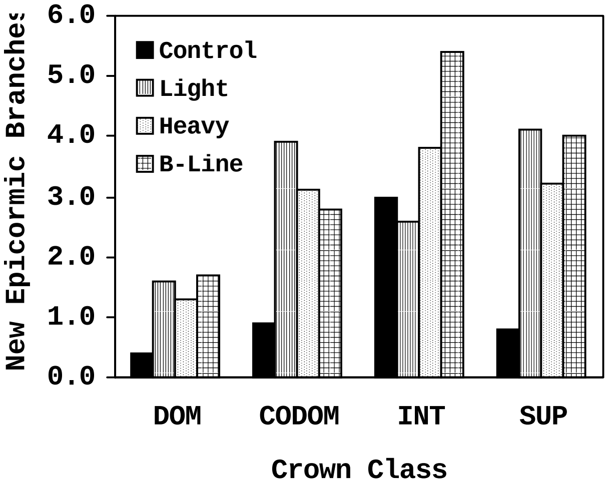


Figure 4–Number of new epicormic branches produced on the butt logs of residual trees, by crown class, during the first 4 years after application of four thinning treatments (DOM=dominant, CODOM=codominant, INT=intermediate, SUP=suppressed).

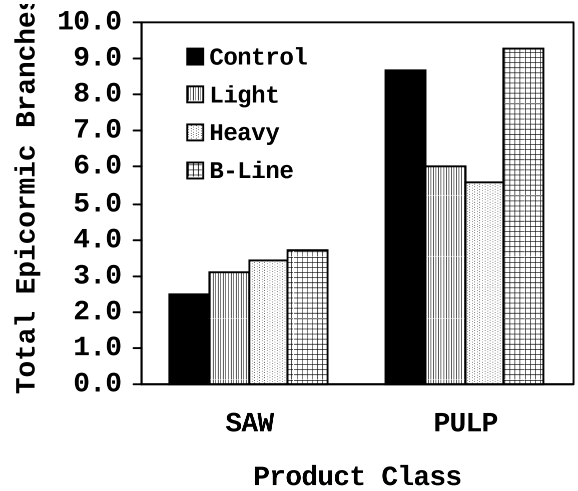


Figure 5–Total number of epicormic branches on the butt logs of residual trees, by product class, 4 years after application of four thinning treatments (SAW=sawtimber, PULP=pulpwood).

example, only B-line thinning increased the production of new epicormic branches on the butt logs of red oaks. In contrast, all levels of thinning greatly increased the production of new epicormic branches on the butt logs of sweetgum trees and more than doubled the number of new epicormic branches on the butt logs of hickories. The observation that the majority of these new branches were produced during the second year following thinning held true across all three species groups. It is important to note that heavy thinning had no significant effect on the production of new epicormic branches on the butt logs of red oaks, even though Meadows (1995) categorized most bottomland red oaks as highly susceptible to epicormic branching. Nearly all of the residual red oaks in the heavily thinned stand were high-vigor, upper-crown-class trees that are generally less likely to produce epicormic branches than are trees in poor health.

Production of new epicormic branches on the butt log also varied among crown classes, across all species (figure 4). In general, new epicormic branches were more frequent on the boles of lower-crown-class trees than on the boles of upper-crown-class trees, especially for trees in the thinned stands. These results support the hypothesis advanced by Meadows (1995) that the tendency for an individual hardwood tree to produce epicormic branches in response to some disturbance or stress is controlled by the species and initial vigor of the particular tree. Meadows (1995) noted that hardwood species vary greatly in their likelihood to produce epicormic branches and provided a classification of the susceptibility of most bottomland hardwood species to epicormic branching. Meadows (1995) also hypothesized that tree vigor is the mechanism that controls the production of epicormic branches when a tree is subjected to some type of disturbance or stress. It follows, then, that healthy, vigorous trees, even of susceptible species, are much less likely to produce epicormic branches than are trees in poor health. Our observations in this study that epicormic branching varied not only by species but also among crown classes strongly support these hypotheses.

When assessing the effects of thinning on epicormic branching, the most important consideration, however, is the total number of epicormic branches found on the butt logs of the crop trees; these are the trees that are favored during the thinning operation and are most likely to produce high-quality sawtimber. Sawtimber trees in the thinned plots averaged 0.6 to 1.2 more epicormic branches on the butt log than sawtimber trees in the unthinned control, when averaged across all species (figure 5). However, these slight increases were not statistically significant. Both light thinning and heavy thinning actually significantly reduced the average number of epicormic branches on the butt logs of pulpwood trees. This reduction may be misleading because we removed most of the pulpwood trees of poor bole quality during the thinning operation.

To carry the analysis one step further, none of the three levels of thinning had a significant effect on the total number of epicormic branches on the butt logs of red oak sawtimber trees 4 years after thinning (figure 6). Red oak sawtimber trees, regardless of treatment, averaged fewer than five epicormic branches on the butt log, generally not enough to result in a reduction in log grade. Sawtimber-sized red oak trees with healthy dominant or codominant crowns apparently are not very susceptible to the production of new epicormic branches following even heavy thinning.

CONCLUSIONS

Stand-level growth and recovery appear to have been somewhat faster after heavy thinning and B-line thinning than after light thinning. In fact, cumulative basal area growth in the heavily thinned stand is now significantly greater than cumulative basal area growth in the lightly thinned stand, such that there is no longer a statistical difference between these two treatments in total basal area 4 years after thinning. Similar, but not statistically significant,

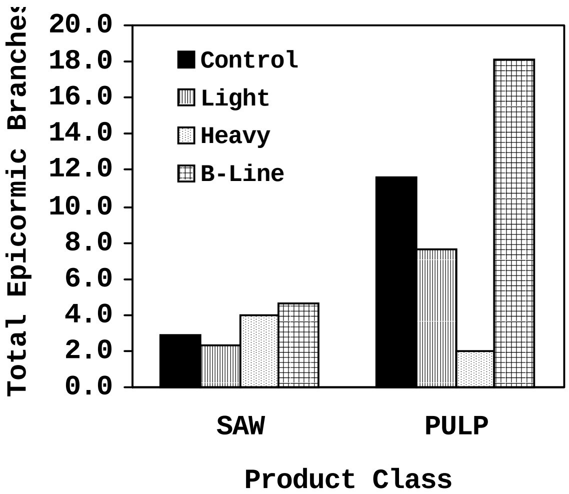


Figure 6–Total number of epicormic branches on the butt logs of red oak residual trees, by product class, 4 years after application of four thinning treatments (SAW=sawtimber, PULP=pulpwood).

increases in both stocking and quadratic mean diameter were observed after both heavy thinning and B-line thinning when compared to light thinning and the unthinned control. Thinning increased diameter growth of residual trees, across all species, but there were only slight differences among the three levels of thinning. Diameter growth response to thinning varied among species groups, with the most pronounced effect observed in red oaks. In fact, all levels of thinning increased cumulative diameter growth of residual red oaks by about 55-58 percent. None of the thinning treatments increased diameter growth of dominant trees, but heavy thinning and B-line thinning increased growth of codominant trees by about 33 percent.

All levels of thinning increased the production of new epicormic branches on the butt logs of residual trees, when averaged across all species, but these increases were relatively small. Thinning had little effect on epicormic branching in red oaks, but greatly increased the production of new epicormic branches in sweetgum. In fact, sawtimber-sized red oaks averaged fewer than five epicormic branches on the butt log 4 years after thinning. This level of epicormic branching is generally not enough to cause a reduction in log grade.

It appears at this time that heavy thinning created a combination of stand density and structure that best promoted rapid stand-level growth and rapid individual-tree diameter growth, with minimal adverse effects on epicormic branching and bole quality of residual trees, especially among red oak crop trees. Heavy thinning removed nearly all of the small-diameter, low-vigor, lower-crown-class trees, whereas the other levels of thinning retained larger proportions of these inferior trees. Consequently, heavy thinning concentrated diameter growth on large, healthy trees that contributed greatly to stand-level growth and minimized the production of new epicormic branches. Both B-line thinning and light thinning retained sufficient numbers of lower-crown-class trees to impede stand-level growth and to increase the risk of epicormic branching.

ACKNOWLEDGMENTS

We express appreciation to Gulf States Paper Corporation for providing the study site and for its cooperation in all phases of study installation and measurement. We specifically thank Sam Hopkins, John Foster, John Tiley, Harry Labhart, John Bryant, and Warren Eatman, all of Gulf States Paper Corporation, for their continuing assistance in this study.

LITERATURE CITED

Broadfoot, Walter M. 1976. Hardwood suitability for and properties of important Midsouth soils. Res. Pap. SO-127. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 84 p.

Goelz, J.C.G. 1995. A stocking guide for southern bottomland hardwoods. Southern Journal of Applied Forestry. 19(3):103-104.

Goelz, J.C.G.; Meadows, J.S. 1997. Stand density management of southern bottomland hardwoods. In: Meyer, Dan A., ed. Proceedings of the 25th annual hardwood symposium; 25 years of hardwood silviculture: a look back and a look ahead; 1997 May 7-10; Cashiers, NC. Memphis, TN: National Hardwood Lumber Association: 73-82.

Hilt, Donald E. 1979. Diameter growth of upland oaks after thinning. Res. Pap. NE-437. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.

Johnson, Robert L. 1981. Wetland silvicultural systems. In: Jackson, Ben D.; Chambers, Jim L., eds. Timber harvesting in wetlands: 30th annual forestry symposium. Baton Rouge, LA: Louisiana State University, Division of Continuing Education: 63-79.

Lamson, Neil I. 1985. Thinning increases growth of 60-year-old cherry-maple stands in West Virginia. Res. Pap. NE-571. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Lamson, Neil I.; Smith, H. Clay. 1988. Thinning cherry-maple stands in West Virginia: 5-year results. Res. Pap. NE-615. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

Lamson, Neil I.; Smith, H. Clay; Perkey, Arlyn W.; Brock, Samuel M. 1990. Crown release increases growth of crop trees. Res. Pap. NE-635. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Marquis, Dave; Smith, Clay; Lamson, Neil [and others]. 1990. Standard plot layout and data collection procedures for the Stand Establishment and Stand Culture Working Groups, Northeastern Forest Experiment Station. [Warren, PA]: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 55 p.

McKnight, J.S. 1958. Thinning stands of water oaks. In: Management of bottomland forests: Proceedings of the seventh annual forestry symposium; 1958 April 10-11; [Baton Rouge, LA]. Baton Rouge, LA: Louisiana State University, School of Forestry: 46-50.

Meadows, James S. 1995. Epicormic branches and lumber grade of bottomland oak. In: Lowery, Glenn; Meyer, Dan, eds. Advances in hardwood utilization: following profitability from the woods through rough dimension: Proceedings of the twenty-third annual hardwood symposium; 1995 May 17-20; Cashiers, NC. [Memphis, TN]: National Hardwood Lumber Association: 19-25.

Meadows, James S. 1996. Thinning guidelines for southern bottomland hardwood forests. In: Flynn, Kathryn M., ed. Proceedings of the southern forested wetlands ecology and management conference; 1996 March 25-27; Clemson, SC. Clemson, SC: Consortium for Research on Southern Forested Wetlands, Clemson University: 98-101.

Meadows, James S.; Goelz, J.C.G. 1998. First-year growth and bole quality responses to thinning in a red oak-sweetgum stand on a minor streambottom site. In: Waldrop, Thomas A., ed. Proceedings of the ninth biennial southern silvicultural research conference; 1997 February 25-27; Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 188-193.

Meadows, James S.; Goelz, J.C.G. 1999. Third-year growth and bole quality responses to thinning in a red oak-sweetgum stand on a minor streambottom site in west-central Alabama. In: Haywood, James D., ed. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16-18; Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 87-93.

Meadows, James S.; Goelz, J.C.G. 2001. Fifth-year response to thinning in a water oak plantation in north Louisiana. Southern Journal of Applied Forestry. 25(1):31-39.

Putnam, John A.; Furnival, George M.; McKnight, J.S. 1960. Management and inventory of southern hardwoods. Agric. Handb. 181. Washington, DC: U.S. Department of Agriculture. 102 p.

Rast, Everette D.; Sonderman, David L.; Gammon, Glenn L. 1973. A guide to hardwood log grading (revised). Gen. Tech. Rep. NE-1. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 31 p.

Sonderman, David L. 1984a. Quality response of even-aged 80-year-old white oak trees after thinning. Res. Pap. NE-543. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

Sonderman, David L. 1984b. Quality response of 29-year-old, even-aged central hardwoods after thinning. Res. Pap. NE-546. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 9 p.

Sonderman, David L.; Rast, Everette D. 1988. Effect of thinning on mixed-oak stem quality. Res. Pap. NE-618. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

SIXTH-YEAR RESULTS FOLLOWING PARTIAL CUTTING FOR TIMBER AND WILDLIFE HABITAT IN A MIXED OAK-SWEETGUM-PINE STAND ON A MINOR CREEK TERRACE IN SOUTHEAST LOUISIANA

Brian Roy Lockhart and Norwin E. Linnartz[1]

Abstract—Hardwood management has primarily focused on highly productive river bottom and upland sites. Less is known about hardwood growth and development on terrace sites. Such sites are usually converted to other uses, especially pine plantations. The objectives of this study, implemented in a minor creek terrace in southeast Louisiana, were to describe changes in stand composition and structure following partial cutting for 3 different management objectives: (1) maximize timber production, (2) maximize wildlife habitat, and (3) to improve timber production and wildlife habitat. Stand composition in 1985 prior to treatment was heavy to oak (72 percent based on importance values) compared to sweetgum (10 percent) and pine (16 percent). Greater diameter growth occurred in the treated plots compared to control 6 years after cutting. Diameter growth differences were also found between crown classes and species groups. Few differences were found in basal area growth between the treatments and the controls while stocking in the treated plots increased relative to the controls. Results indicate that hardwoods will respond to partial cutting on terrace sites, making hardwood or mixed pine-hardwood management options viable.

INTRODUCTION

Bottomland hardwood forest cover types (oak-gum-cypress and elm-ash-cottonwood) cover about 34 percent, or 4.7 million acres, of Louisiana's forested land based on the last U.S. Forest Service state forest inventory (Vissage and others 1991). Combined with the upland hardwood types (oak-hickory and oak-pine), hardwood-dominated forests cover 8.7 million acres or 63 percent of Louisiana's forested land (33 percent of Louisiana's total land base; Vissage and others 1991). Current hardwood acreage estimates are unknown. While land clearing for agriculture has continued, especially in the Mississippi Alluvial Plain, the rate of clearing has slowed. Furthermore, the trend to clear hardwood forests for agriculture may have been offset or even reversed since the last forest survey due to land being replanted to hardwoods, primarily under the Conservation Reserve Program and the Wetlands Reserve Program (Stanturf and others 1998). The vast acreage dominated by hardwood species, combined with the value of quality hardwood for both timber and wildlife habitat, attests to the tremendous opportunity for hardwood management in Louisiana, especially when one considers that hardwood lumber production accounted for only 1.91 million bf of the 1.148 billion bf harvested in Louisiana in 1999 (based on severance tax collections; Louisiana Office of Forestry web site - http://www.ldaf.state.la.us/forestry/index.htm).

Hardwood management in the southern United States has focused either on bottomland sites, especially first bottoms (Putnam and others 1960, Walker and Watterston 1972, Kellison and others 1981), or upland sites, especially in mountainous regions (Walker 1972, Smith and Eye 1986, Smith and others 1988). Less is known about hardwood growth and development on terrace sites. Terrace sites, often called second or even third bottoms, were former floodplains before the stream system moved to a lower elevation. These sites seldom flood, becoming inundated only in extremely high flood events. Therefore, terrace soils are usually well developed including argillic and fragipan horizons. Hodges (1997) stated that terrace sites can support hardwoods, but their growth and quality are generally not as good as active floodplain sites due to leaching of nutrients (and lack of nutrient recharge from flood events), development of pan horizons which restrict root development, and less favorable soil moisture relationships. Oftentimes terrace sites are bedded then converted to pine plantations. With the need for more information on hardwood management, particularly on terrace sites, a study was implemented to determine the growth and development of hardwood species on a terrace site using three different management objectives. Sixth-year results are reported.

MATERIALS AND METHODS

Study Site

The study site is located along Sandy Creek at the Idlewild Research Center, East Feliciana Parish, near Clinton, LA. Early 1940s photographs indicated the site was of old-field origin with scattered pine trees (Clifton 1987). The site also burned sometime prior to 1959 which resulted in a large number of multiple-stemmed hardwood trees due to resprouting.

[1]Associate Professor and Professor Emeritus, School of Forestry, Wildlife, and Fisheries, Louisiana Agricultural Center, Louisiana State University, Baton Rouge, LA 70803, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Initial characteristics of major species in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana. Importance values are the sum of relative density and relative dominance (basal area)

Species	Trees per acre	Basal area (ft^2) per acre	Relative Density	Relative Dominance	Importance Value
sweetgum	19.54	5.27	12.80	6.48	19.28
loblolly pine	11.30	17.59	7.40	21.61	29.01
white oak	16.62	5.79	10.89	7.11	17.99
water oak	43.39	19.73	28.42	24.24	52.65
cherrybark oak	13.76	7.38	9.01	9.07	18.08
willow oak	34.02	20.17	22.28	24.78	47.07
other species[1]	14.06	5.47	9.20	6.71	15.92
Totals	152.69	81.40	100.00	100.00	200.00

[1] Other species include red maple, American hornbeam, pignut hickory, flowering dogwood, green ash, yellow-poplar, southern magnolia, crab apple, blackgum, sourwood, shortleaf pine, spruce pine, black cherry, southern red oak, swamp laurel oak, swamp chestnut oak, post oak, sassafras, horsesugar, winged elm, and American elm.

Four soil series were present on the study site (in order of magnitude): Calhoun silt loam, 65 percent (Typic Glossaqualf); Providence silt loam, 25 percent (Typic Fragiudalf); Bude silt loam, 5 percent (Glossaquic Fragiudalf); and Cascilla silt loam, 5 percent (Fluventic Dystrochrept). The first 3 soils were formed in loess or in a silty mantle, contained argillic horizons (2 had fragipan horizons), and were considered somewhat poorly drained to moderately well drained. The Cascilla silt loam was formed in silty alluvium, contained no pans, and was well drained.

Site index, base age 50 years, was estimated to be about 90 feet for cherrybark oak (*Quercus pagoda* Raf.), water oak (*Q. nigra* L.), and willow oak (*Q. phellos* L.) across the site, 115 feet for loblolly pine (*Pinus taeda* L.) on the Calhoun silt loam and 107 feet on the Providence silt loam. Average age for the oaks at the time of study installation was about 36 years with the scattered pine representing a second, older age class (Clifton 1987).

Study Design

In the Fall 1985, fourteen 2.541-acre (1-hectare) square plots were established in the stand. Each plot was surrounded by a 50-foot buffer strip. Species composition at the time of establishment was primary oak [importance value (sum of relative density and relative dominance) of 144; water, willow, white (*Q. alba* L.), cherrybark, swamp laurel (*Q. laurifolia* Michx.), swamp chestnut (*Q. michauxii* Nutt.), post (*Q. stellata* Wang.), and southern red (*Q. falcata* Michx.); table 1]. Other important species included sweetgum (importance value 19; *Liquidambar styraciflua* L.), and pines (importance value 31; shortleaf (*P. echinata* Mill.) and spruce (*P. glabra* Walt.) and loblolly).

Three treatments with 4 replications and a control with 2 replications were randomly assigned to these plots using a randomized incomplete block design (RIBD). These treatments are described below.

Timber—The timber treatment objective was to improve tree growth for timber production (veneer and sawlogs) by using a combination of crown thinning and improvement cutting to provide growing space for desirable trees (primarily red oaks). Trees marked for harvest were less-desirable species, suppressed, diseased, damaged, or otherwise poor candidates to remain until the next stand entry.

Wildlife Habitat—The wildlife habitat treatment objective was to improve wildlife habitat through a combination of crown thinning and improvement cutting to favor those tree species known to benefit wildlife populations regardless of tree quality relative to timber production. Mast-producing trees and cull and den trees were favored during marking. Also, one small opening, about 0.25 acre, was created in the plot center by severing all remaining trees $\leq$ 4 inches d.b.h. following harvesting of the overstory trees.

Timber/Wildlife Habitat—The third treatment involved combining the objectives of the first two treatments through a combination of crown thinning and improvement cutting for quality timber production and wildlife habitat. No small openings were made specific for the wildlife habitat objective aspect as in the wildlife habitat treatment.

All marking was done by developing tree class criteria (preferred stock, reserved stock, bolt stock, cutting stock, and culls; Putnam and others 1960, Dicke and others 1989) specific to each objective. Marking for the timber objective was conducted by a professional forester while marking for the wildlife habitat treatment was conducted by a professional wildlife biologist. These 2 individuals worked together to mark the combined timber/wildlife habitat treatment. Harvesting was conducted during late March to early June 1986 with a follow-up felling of all remaining marked trees.

Pre-harvest tree measurements were conducted during the Winter 1985/1986 and included species identification, d.b.h., crown class (Smith 1986), and tree class. Afterwards, all trees $\geq$ 4 inches were tagged at d.b.h. for future reference. Annual d.b.h. measurements were taken during the dormant season for the next 6 years. Trees that died each year were noted along with trees that grew into the 4-inch d.b.h. class ($\geq$ 3.6 inches).

Analyses involved using analysis-of-variance (ANOVA) in the RIBD. An alpha level of 0.10 was used to determine significance and Duncan's Multiple Range test was used to

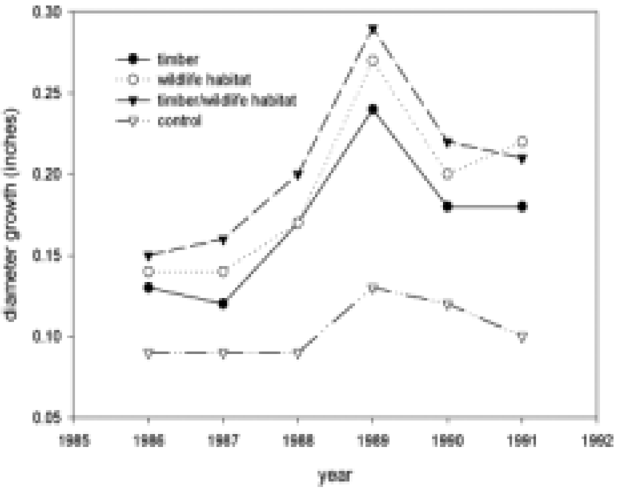


Figure 1—Annual diameter growth (inches) by management objective over a 6-year period following partial cutting in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana.

detect differences between treatments if the initial ANVOA was significant. Dependent variables tested included annual diameter and basal area growth, 6th-year diameter and basal area increment (referred to as cumulative growth), and stocking using Goelz (1995) stocking charts for bottomland hardwoods. These variables were tested for all trees combined, by crown class, and by 3 species groups (red oaks, white oaks, and pines). All measurements were taken in metric units then converted to English units for analyses and presentation. Scientific names follow Duncan and Duncan (1988).

Table 2—Cumulative diameter and basal area growth and changes in stocking over a 6-year period following partial cutting in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana.

Treatment	Diameter inches	Basal Area sq. ft./acre	Stocking percent
Timber	1.04a[1]	17.54	7.6a
Wildlife Habitat	1.16a	16.53	6.5a
Timber/Wildlife Habitat	1.25a	17.30	8.5a
Control	0.65b	15.22	-0.1b
p-values	.0128	.7139	.0367

[1] Means followed by different letters within a column are significantly different at p=0.10.

RESULTS AND DISCUSSION

Diameter Growth

Diameter growth averaged about 0.10-0.25 inches per year across the study site. In general, tree diameter growth in any given growing season was greater for the treated plots compared to the controls (figure 1). Exceptions included 1986 when only the timber/wildlife habitat treatment was greater than the controls, and 1987 and 1990 when both the wildlife habitat and timber/wildlife habitat treatments were greater than the controls. A general trend of increasing diameter growth occurred each year during the first 4 years following study installation (figure 1). This increasing response may reflect increasing crown area in the residual trees and thus increased photosynthate production and/or better climatic conditions.

Table 3—Cumulative diameter growth by crown class over a 6-year period following partial cutting in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana

Treatment	Crown Class dominant	codominant	intermediate	suppressed
timber	1.89a[1]	1.25a	0.72ab	0.53ab
wildlife habitat	1.71a	1.40a	0.76ab	0.82a
timber/wildlife habitat	1.81a	1.41a	0.93a	0.86a
control	1.36b	0.99b	0.47b	0.27b
p-values	.0373	.0305	0.586	.0237

[1] Means followed by different letters within a column are significantly different at p=0.10.

Table 4—Cumulative diameter growth (inches) by species group (see text for individual species within each species group) over a 6-year period following partial cutting in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana

	Species Group		
Treatment	red oaks	white oaks	pines
Timber	1.18a[1]	0.76ab	1.87a
Wildlife Habitat	1.23a	0.89ab	1.98a
Timber/Wildlife Habitat	1.34a	1.02a	1.91a
Control	0.82b	0.43b	1.41b
p-values	.0069	.1780	.1836

[1] Means followed by different letters within a column are significantly different at p=0.10.

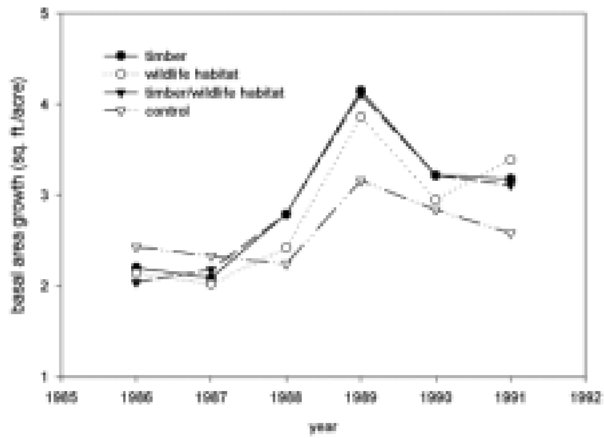


Figure 2—Annual basal area growth (square feet/acre) by management objective over a 6-year period following partial cutting in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana.

Cumulative diameter growth for all trees after 6 growing seasons was about 1-1.25 inches for the harvested treatments compared to only 0.65 inches for the controls (table 2). The cumulative diameter growth for the treated plots correspond to 1.75-2 inches of diameter growth over a 10-year period which is well below the 4-6 inches per decade considered indicative of a highly productive bottomland hardwood site (Briscoe 1955).

Cumulative diameter growth by crown class showed that dominant trees had greater growth compared to the codominant, intermediate, and overtopped crown classes (table 3). This was not unexpected given that dominant trees have larger, more healthy crowns compared to trees in the other crown classes. Codominant trees had the second largest cumulative diameter growth while no difference in cumulative diameter growth occurred between the intermediate and overtopped classes. As with cumulative diameter growth for all trees by treatment, growth was greater within a crown class for the treated plots compared

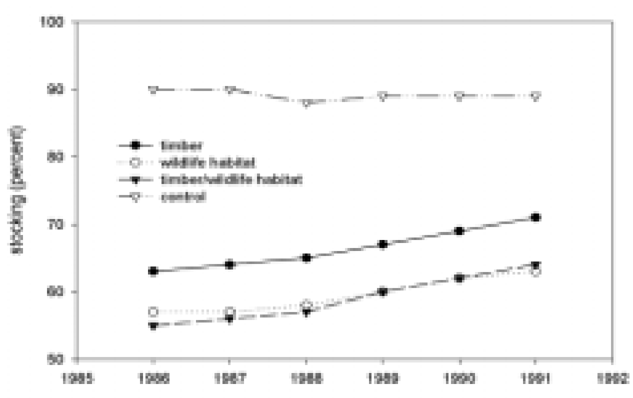


Figure 3—Changes in stocking (percent) by management objective over a 6-year period following partial cutting in an oak-sweetgum-pine stand, Idlewild Research Station, East Feliciana Parish, southeast Louisiana.

to the controls. Among species groups, the pines had greater cumulative diameter growth compared to the red oak and white oak groups with red oaks having greater growth than white oaks (table 4).

Basal Area Growth

Basal area growth averaged 2.78 square feet per acre per year between the partial cutting treatments and controls. Few differences occurred in basal area growth between the treatment and controls; exceptions being in 1988 when the timber and timber/wildlife habitat treatments had greater growth compared to the controls and 1991 when all 3 partial cutting treatments had growth greater than the controls (figure 2). No differences were found in the 6-year cumulative basal area growth between the treatments and the controls (table 2). No differences were also found in cumulative basal area growth between treatments and controls within each of the 4 crown classes or the 3 species groups. While treated plots had greater diameter growth, the control plots had a greater number of trees per acre to match the increases in basal area growth in the treated plots.

Stocking

Stocking was evaluated using Goelz (1995) stocking equation for southern bottomland hardwoods. Goelz (1995) noted that this equation was developed from Putnam and others (1960) table for stocking of an even-aged bottomland hardwood forest and not on long-term replicated research. Furthermore, since the present study was conducted on a well-developed terrace, and not on an active floodplain (Hodges 1997), applicability of Goelz's (1995) stocking equation to this type of site may be questionable.

Initial stocking in the control plots average 89 percent. Stocking for the treated plots was less because only post-harvest d.b.h. measurements, but pre-1986 growing season, were conducted (figure 3). Stocking remained about 89 percent for the control plots throughout the 6-year study period (figure 3). Changes in stocking for the treated plots showed a fairly consistent pattern with stocking in the timber objective treatment always being greater than in the wildlife habitat and timber/wildlife habitat treatments. This difference was due to the greater initial stocking in the timber objective treatment. No difference occurred in the change in stocking over the 6-year study period for the partial cutting treatments, averaging about 1-1.5 percent increase per year (table 2).

CONCLUSIONS

Several conclusions can be made based on the results from partial cutting in hardwoods growing on a terrace site.

First, hardwoods growing on a terrace site such as the one found on the Idlewild Research Center will respond to partial cutting, especially red oak species. One can expect about 2 inches of diameter growth per decade, 3 square feet of basal area growth per year, and about a 1 percent increase in stocking per year.

Second, pines, especially loblolly pine, grew better than hardwoods on the terrace site in this study. Intensive culture of pines, such as bedding and use of genetically-improved seedlings, would result in even better growth.

Third, few differences were found between the timber, wildlife habitat, and timber/wildlife habitat treatments, at least in terms of diameter and basal area growth. Assessments of log quality, financial returns, and specific wildlife habitat measures, such as mast production, quantity and quality of browse material, and vertical and horizontal structure, must be made before more definite comparisons can be made regarding treatment effects. The important point is to have specific management objectives stated before commencing silvicultural operations.

Finally, when determining management objectives, especially regarding decisions to convert terrace hardwoods to pines, keep in mind that hardwoods will grow on such sites, making mixed pine-hardwood management options viable. Furthermore, in afforesting pastures on terrace sites, planting pine and allowing hardwoods to develop underneath the pine following natural successional tendencies may constitute a viable “hardwood rehabilitation” option.

REFERENCES

Briscoe, C.B. 1955. Diameter growth of selected bottomland hardwoods as affected by species and site. LSU Forestry Notes #5, Baton Rouge, LA: Louisiana State University, 2 p.

Clifton, J.R. 1987. First-year tree growth and stand characteristics after an initial thinning-improvement cutting in a pole-sized natural hardwood stand. Baton Rouge, LA: Louisiana State University. 86 p. Masters thesis.

Dicke, S.G.; Linnartz, N.E.; Clifton, J.R. 1989. Early response of a mixed oak-gum-pine stand to improvement cuttings. In: Miller, J.H., comp. Proceedings of the fifth biennial southern silvicultural research conference; 1988 November 1-3; Memphis, TN. Gen. Tech. Rpt. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Experiment Station: 303-307.

Duncan, W. H.; Duncan, M.B. 1988. Trees of the southeastern United States. Athens, GA: The University of Georgia Press. 322 p.

Goelz, J.C.G. 1995. A stocking guide for southern bottomland hardwoods. Southern Journal of Applied Forestry. 19: 103-104.

Hodges, J.D. 1997. Development and ecology of bottomland hardwood sites. Forest Ecology and Management. 90: 117-125.

Kellison, R.C.; Federick, D.J.; Gardner, W.E. 1981. A guide for regenerating and managing natural stands of southern hardwoods. Raleigh, NC: North Carolina Agricultural Research Service. 24 p.

Putnam, J.A.; Furnival, G.M.; McKnight, J.S. 1960. Management and inventory of southern hardwoods. Agric. Handb. 181. Washington, DC: U.S. Department of Agriculture. 102 p.

Smith, D.M. 1986. The practice of silviculture, 8th edition. John Wiley. 527 p.

Smith, H.C.; Eye, M.C. (eds.). 1986. Proceedings: guidelines for managing immature Appalachian hardwood stands. 1986 May 28-30, Morgantown, WV, Publication 86-02. Bethesda, MD: Society of American Foresters. 283 p.

Smith, H.C.; Perkey, A.W.; Kidd, W.E.,Jr. (eds.). 1988. Proceedings: guidelines for regenerating Appalachian hardwood stands. 1988 May 24-26, Morgantown, WV, Publication 88-03. Bethesda, MD: Society of American Foresters. 293 p.

Stanturf,J.A.; Schweitzer,C.J.; Gardiner,E.S. 1998. Afforestation of marginal agricultural land in the Lower Mississippi River Alluvial Valley, U.S.A. Silva Fennica. 32: 281-297.

Vissage, J.S.;Miller, P.E.; Hartsell, A.J. 1992. Forest statistics for Louisiana Parishes - 1991. Res. Bull. SO-168. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 65 p.

Walker, L.C. 1972. Silviculture of southern upland hardwoods. Bulletin 22. Nacogdoches, TX: Stephen F. Austin State University. 137 p.

Walker, L.C.; Watterson, K.G. 1972. Silviculture of southern bottomland hardwoods. Bulletin 25. Nacogdoches, TX: Stephen F. Austin State University. 78 p.

AMERICAN CHESTNUT, RHODODENDRON, AND THE FUTURE OF APPALACHIAN COVE FORESTS

D.H. Van Lear, D.B. Vandermast, C.T. Rivers, T.T. Baker, C.W. Hedman, D.B. Clinton, and T.A. Waldrop[1]

Abstract—By the mid 1930s, the southern Appalachians had been heavily cutover and the dominant hardwood, American chestnut (Castanea dentata), had succumbed to the chestnut blight (Cryphonectria parasitica). Forests that had been burned on a frequent basis for millennia were now protected and fire was excluded in large degree. We estimated the pre-blight importance of chestnut in cove forests and the recovery of the overstory canopy on these rich sites following the blight and logging early in the last century. The overstory has largely recovered from the blight, although chestnut is not longer a functional component of the cove forest ecosystem. Following the blight, the successional pathway on two unlogged, old-growth sites proceeded to an oak association; on two logged sites, succession proceeded to mesophytic forests. A gradual change in the understory has occurred in many coves that threatens their future diversity and productivity. Encroaching rhododendron (Rhododendron maximum) thickets are severely inhibiting hardwood regeneration and reducing herbaceous/shrub species richness. Neither shade-tolerant nor shade-intolerant hardwood species are becoming established in canopy-gaps where rhododendron is present in moderate to high densities. Rhododendron has become an ecologically dominant species because it thrives on disturbance and, once established, inhibits other species. New management techniques will have to be developed if diversity and productivity of cove hardwood forests are to be sustained.

INTRODUCTION

Throughout the past century, hardwood forests of the southern Appalachians have undergone major changes as they recovered from heavy logging, loss of American chestnut to a blight, and exclusion of frequent fires. Nearly all of the southern Appalachian Mountains were heavily cutover between 1880 and 1930. The chestnut blight (*Cryphonectria parasitica*), introduced in the Northeast in the early 1900s and regarded as the most devastating ecological event ever recorded in the southern Appalachians, essentially removed that species as a canopy dominant by the late 1930s. Recovery of the forest overstory following the blight is well documented (Keever1953, Nelson 1955, Woods and Shanks 1959, Runkle 1982); however, effects of chestnut's demise on shrub and herb synusia have rarely been described.

Another major disturbance that shaped the current composition and structure of the region's forests was the exclusion of frequent fire as an ecological process. Exclusion of fire is regarded as a disturbance because it is a deviation from the normal burning regime that existed in the southern Appalachians for millennia. Burning by native Americans would have created a mosaic of vegetative conditions but the general appearance would have been a more open forest with a greater abundance of herbaceous vegetation (Van Lear and Waldrop 1987, Barden 1997, Delcourt and Delcourt 1997). Exclusion of fire allowed rhododendron (*Rhododendron maximum*), an ericaceous woody shrub, to extend its influence far beyond the streamsides where it occurred at the turn of the past century (Ayres and Ashe 1902, Monk and others 1985).

Expansion of rhododendron is a concern for hardwood forest managers because recruitment of canopy tree seedlings is inhibited under the dense cover of rhododendron (Hedman and Van Lear 1994, Clinton and others 1994, Clinton and Vose 1996, Baker and Van Lear 1998). It is debatable whether hardwood seedlings, once established, can grow through rhododendron thickets and become overstory trees, thereby sustaining the diversity and productivity of cove forests. The density and size of rhododendron thickets determines whether hardwood seedlings can successfully become established.

[1]Bowen Professor of Forestry, Department of Forest Resources, Clemson University, Clemson, SC 29634; Graduate Student, Department of Biology, University of North Carolina, Chapel Hill, NC 27599-3280; Forester, International Paper Company, Jackson, MS; Extension Riparian Management Specialist, College of Agriculture and Home Economics, New Mexico State University, Las Cruces, NM 88003-8003; Ecosystem Project Forester, International Paper Company, Bainbridge, GA 32717; Research Forester, US Forest Service, Southern Research Station, Coweeta, NC 28763; Research Forester, US Forest Service, Southern Research Station, Clemson, SC 29634, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

This paper summarizes results of several separate, but related, studies conducted over the past decade in cove/riparian forests of the southern Appalachians. Our objectives were to: 1) quantify the importance of pre-blight chestnut in these forests, 2) describe forest recovery following logging and the chestnut blight, with special emphasis on the understory and regeneration layers, 3) identify relationships between density of rhododendron thickets and species richness/ regeneration, and 4) examine effects of rhododendron on canopy-gap dynamics and establishment of forest regeneration. All studies were conducted on the lower slopes of coves, i.e., riparian forests, within 35 meters of a stream. From this point, we will call these cove forests.

METHODS

Study Areas

All studies were conducted in the Blue Ridge physiographic province of the southern Appalachians. Study sites were located on the Sumter National Forests in South Carolina, the Chattahoochee National Forest in Georgia, and the Pisgah and Nantahala National Forests in North Carolina. Soils on these sites are classified as Typic Dystrochrepts, and are commonly 50-152 centimeters deep. This area experiences a temperate humid climate with a growing season of approximately 180 days. Most of the ample precipitation occurs in the growing season.

Methods for each of the studies are summarized below. Refer to published papers by the authors for greater detail on methods. In this paper, rhododendron refers to *Rhododendron maximum*, which was by far the most dominant ericaceous shrub on study sites.

Chestnut's Importance in Cove Forests

Four forest sites containing chestnut were selected along first- or second-order streams (elevations 363 to 780 meters). Two of the sites, Thomas Creek and Tallulah River, showed signs of chestnut salvage logging and general logging in the past, while the other two sites, Slatten Branch and Little Santeetlah Creek, were remnant old-growth stands with no evidence of ever having been logged. All identifiable chestnut snags were measured for ground-line diameter (GLD) and diameter breast height (DBH), where possible, along stream reaches ranging in length from 363-780 meters. A total linear distance of 3.1 kilometers was surveyed on the four sites, representing 16.4 hectares of southern Appalachian cove forests (Vandermast and Van Lear 2001).

We identified 589 chestnut snags and stumps in the riparian forests of the four study sites, 207 of which were intact enough to obtain accurate DBH data. Using the derived linear relationship between DBH and ground-line diameter ($R^2 = 0.947$), we estimated DBH of the remaining chestnuts whose ground-line diameter only could be estimated.

Forest Recovery Following the Blight and Logging

Composition of the current cove forest at the four sites was determined by sampling 7x 7 meter plots centered around 58 randomly selected chestnut stumps or snags (10 percent of the 589 identified). Herbaceous vegetation was sampled within five 1 square-meter quadrats in each plot. Trees and seedlings were tallied by species on 0.04 hectare plots and saplings on 0.025 hectare plots using the Braun-Blaunquet cover class method. Rhododendron stems were counted in each 0.04 hectare plot.

Species richness was calculated and compared among sites and between old-growth and logged sites. Frequency values, i.e., the proportion of plots containing a species, were used to compare old-growth to logged forests and to compare plots with high and low rhododendron importance values. Regeneration of overstory hardwood species was regressed against rhododendron coverage (Vandermast and Van Lear 2001).

Relationships Between Rhododendron Coverage and Species Richness

Fifty-five 10x20 meter plots were randomly located along Wine Spring Creek in the Nantahala National Forest. All stems > l centimeter basal diameter were recorded by species in each plot. Average dbh, density, basal area, and importance value (relative density + relative basal area/2) were calculated for each species by canopy strata. Diameter of each rhododendron stem was measured and placed into l centimeter diameter classes. Biomass of rhododendron foliage and stems was estimated from allometric equations developed from 41 randomly chosen stems ranging from 1 to 4 centimeters basal diameter.

The regeneration layer (woody and herbaceous stems < 1 centimeter basal diameter) was inventoried on five transects, each 10 meter long, across the width of each plot. Frequency and percent cover of each species that intersected the transect were recorded by 1 meter intervals and importance values (relative frequency + relative coverage/2) were calculated. Discriminant analysis, using basal area and stem density, was used to quantitatively classify the 55 sample plots into four discrete rhododendron thicket-density categories (Baker and Van Lear 1998).

Effects of Rhododendron on Canopy-Gap

Dynamics

Twenty-two canopy gaps (elevations from 518 to 758 meters) resulting from wind-throws were selected in southern Appalachian cove forests. Eleven of the canopy gaps contained understories of rhododendron with a minimum density of 2000 stems/hectare and eleven other gaps contained no rhododendron. Selected gaps had to meet certain criteria, including 1) being less than 7 years old, 2) occupying only mesic site types, and 3) being within 35 meters of a stream. Gap size ranged from one-tree openings to larger gaps resulting from the death of up to six trees (Rivers and others 2000).

Vegetation was sampled along two gradients: 1) longest distance across the gap, and 2) a shorter distance perpendicular to the first. The two gradient lines intersected at the center of the gap. Advanced regeneration and new seedlings were inventoried in 1 meter wide transects located along each of the two principle gradient lines. Transects

Table 1—Mean diameter (DBH) and basal area (BA) for chestnuts and live trees on four southern Appalachian cove forest sites

Site	Chestnut		Live Trees	
	DBH (cm)	BA/ha (m^2)	DBH (cm)	BA/ha (m^2)
Old-growth				
Slatten Branch	56.2a[a]	8.9a	26.2a	22.7a
Little Santeetlah	73.7c	12.3c	28.6a	37.5a
Logged				
Thomas Creek	43.9b	8.4b	26.9a	28.8a
Tallulah River	53.6a	10.0a	27.6a	32.9a

[a] Means followed by the same letter within a column are not significantly different at the 0.01 level.

were divided into 1 meter sections to distinguish vegetative preference from the center of the gap towards the surrounding undisturbed forest. Percent cover of rhododendron was estimated and placed into Braun-Blaunquet category classes for each 1 square-meter section and averaged to determine total percent cover for each gap. The area of a gap was determined using the formula for an ellipse.

All stems < 10 centimeter ground-line-diameter were considered understory and all stems > 10 centimeter gld were considered either midstory or overstory. Stems < l centimeter were considered part of the regeneration layer. Importance Values were calculated as described above.

Statistical Analyses

Chestnut and current live stem diameters and basal areas were compared among logged and old-growth sites using PROC GLM and Analysis of Variance in SAS (SAS Institute,

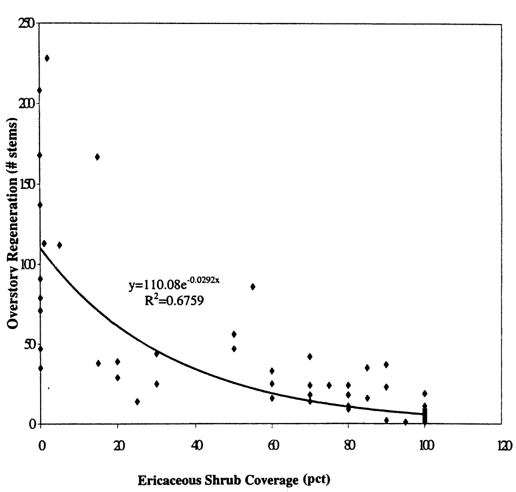


Figure 1—Effects of increasing ericaceous shrub coverage (predominantly *Rhododendron maximum*) on a number of regeneration stems (seedlings and saplings) of overstory tree species on 0.04 hectacre plots

Inc. 1987). Tukey's Least Significant Difference Test and orthogonal contrasts were used to make specific tests. Regression analysis was used to develop a model predicting chestnut DBH from ground-line diameters. Forest recovery plots were clustered based on similar vegetative composition using Detrended Correspondence Analysis (DECORANA) and Two-way Indicator Species Analysis (TWINSPAN) (Hill 1970). Discriminant analysis was used to categorize Wine Spring Creek plots into different levels of rhododendron-thicket densities using PROC DISCRIM (SAS Institute, Inc. 1987). Differences in regeneration layer richness and cover among rhododendron density categories were tested with PROC GLM. Non-linear regression was used to quantify relationships between species richness and rhododendron coverage in canopy gaps.

RESULTS

Chestnut's Importance in Riparian Forests

Chestnut was an important component of southern Appalachian cove forests (table 1). Average DBH of standing chestnut snags was about 2 - 2.5 times larger than that of live trees currently growing on old-growth and logged sites (Vandermast and Van Lear 2001). Chestnut basal area ranged from 8.9 to 12.3 square meters per hectare, suggesting that the species represented between 25 to 40 percent of the pre-blight lower cove forest if current conditions are similar. Old-growth sites tended to have larger diameter trees than logged sites, although only chestnuts on Little Santeetlah Creek were significantly larger.

Following the Blight and Logging

On unlogged, old-growth sites, current overstory composition indicates forest succession following the chestnut blight produced an oak association with a component of mesophytic species such as Eastern hemlock (*Tsuga canadensis*) and black birch (*Betula lenta*) (Vandermast and Van Lear 2001). On logged sites, current overstory composition is dominated by cove mesophytic species, such as yellow-poplar (*Liriodendron tulipifera*), black birch, red maple (*Acer rubrum*), and Eastern hemlock. Seedling-sized sprouts of American chestnut are still common in these riparian forests, although no sapling-sized sprouts were tallied. Chestnut sprouts were absent in rhododendron thickets, which were significantly denser in logged forests. Overstory regeneration (seedlings and saplings) was negatively impacted by rhododendron (figure 1), decreasing exponentially as rhododendron coverage increased. The only species capable of successfully regenerating in dense rhododendron thickets was Eastern hemlock, and even this shade-tolerant conifer had low stem densities when rhododendron density was high. Rhododendron was ubiquitous on both the logged and old-growth sites, occurring on 81 to 90 percent of the 58 plots. The two logged sites had significantly denser rhododendron thickets ($p = 0.0094$) than the two-old growth sites.

Relations Between Rhododendron Coverage and Species Richness

Density and biomass of rhododendron were characterized in the understory of a second-growth riparian forest dominated by yellow birch (*Betula alleghaniensis*) and black birch (age about 42 - 44 years old) (Baker and Van Lear 1998).

Table 2—Range of rhododendron stem density and biomass in each thicket density category

Rhododendron thicket density	Stem density (thousands/hectare)	Above-ground biomass (tons/hectare)
High	8.0 - 17.4	18.1 - 34.0
Medium	5.1 - 10.5	8.7 - 18.3
Low	2.8 - 6.5	2.9 - 8.4
Scarce	0.0 - 2.6	0.0 - 3.0

Table 3—Effects of rhododendron density on species richness in the regeneration layer during Fall and Spring sampling periods

Rhododendron thicket density	Richness (# species)	
	Fall	Spring
High	6a[a]	7a
Medium	9ab	12b
Low	18c	22c
Scarce	26d	29d

[a] Means followed by the same letter within a column are not significantly different at the 0.01 level.

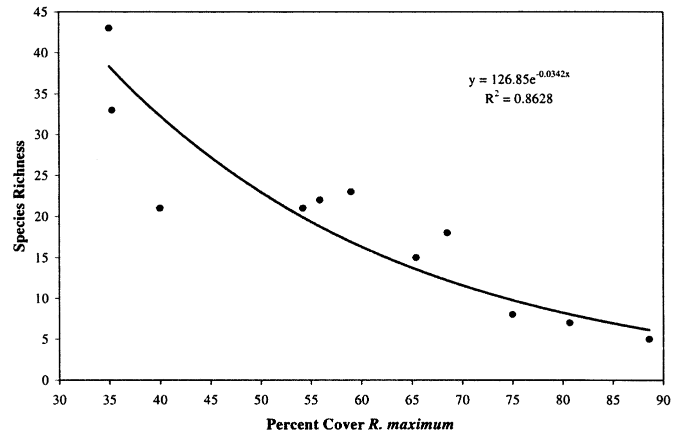


Figure 2—Relation between species richness and percent cover of rhododendron in southern Appalachian forest gaps

Rhododendron densities exceeded 17,000 stems per hectare in high coverage plots and biomass reached 34 tons per hectare (table 2). Basal area of rhododendron thickets averaged 11 - 22 square meters per hectare where thicket density was high.

Total species richness in the regeneration layer and percent rhododendron cover were inversely related ($R^2 = 0.92$) (Baker and Van Lear 1998). On average, 6-7 plant species were found on plots with high densities of rhododendron whereas 26-29 species were found where rhododendron was scarce or absent (table 3). Cover of species other than rhododendron ranged from 5 percent where rhododendron density was high to 43-62 percent where its density was classified as scarce. Similar relationships were found by Hedman and Van Lear (1994) and Vandermast and Van Lear (2001).

Based on aging of stems through ring counts, rhododendron apparently began to dominate the understory of this birch-dominated forest on Wine Spring Creek within 15-20 years after logging (Baker and Van Lear 1998). It has increased in density and coverage and is now so dominant in terms of number of stems, basal area and biomass that it appears doubtful that valuable hardwood species such as yellow-poplar, yellow and black birch, black cherry (*Prunus serotina*), sugar maple, basswood (*Tilia americana*), yellow buckeye (*Aesculus octandra*), Fraser magnolia (*Magnolia fraseri*), and others will be able to establish themselves. In the regeneration layer of rhododendron thickets on the Wine Spring Creek site, Eastern hemlock, red maple, American beech (*Fagus grandifolia*), yellow birch, and Northern red oak (*Quercus rubra*) were present in small numbers. However, rhododendron so dominated the regeneration and understory layers that it appeared unlikely that many of these will reach midstory and overstory strata.

Effects of Rhododendron on Canopy-Gap Dynamics

Average canopy gap size in this study was 157 square meters (range 41 to 286 square meters). Species richness decreased exponentially as rhododendron coverage increased in canopy gaps (figure 2). Average midstory density, an indicator of whether woody species are becoming established in the stand, was 10 fold less in gaps containing rhododendron. Where rhododendron was present prior to gap formation, there was little advanced regeneration and, if present, it was not developing into the midstory. Herbaceous density was even more adversely affected by the presence of rhododendron in gap understories.

As density of the rhododendron understory increased under canopy gaps, shade- intolerant species such as yellow-poplar were eliminated and shade-tolerant species such as sugar maple were severely reduced to levels where little or no recruitment into the overstory occurred (Rivers and others 2000). Eastern hemlock, an extremely shade-tolerant conifer, was the only species capable of regenerating in canopy gaps where moderately dense rhododendron thickets occurred, and even here hemlock tended to regenerate in small patches where rhododendron coverage was lower. Maximum above-ground biomass of rhododendron measured in this study was 37 tons per hectare, similar to that estimated in an earlier study by Baker and Van Lear (1998).

Average tree seedling height was greater in gaps without rhododendron than in those with it, except for intolerant species near the gap edge where shading from the adjacent overstory reduced growth. Seedling height of intolerant species like yellow-poplar and sweet birch significantly decreased as distance from the center of the gap increased, whereas height of shade-tolerant species like red maple and Eastern hemlock varied little along gap gradients.

DISCUSSION

Due to its sensitivity to frost, glaze, and ice (Parker et al. 1993), American chestnut has been thought to be unsuited for ravines and valleys. Chestnut was most often listed as a dominant species on ridges (Abrams and Ruffner 1995, Abrams and McCay 1996) and mid-slope areas (Whitaker 1956). While recognized as a member of cove forests (Ayers and Ashe 1902, Woods and Shanks 1959, Lorimer 1980, McCarthy and Bailey 1996), chestnut had never been quantitatively described in cove forests.

American chestnut was clearly a dominant tree in southern Appalachian cove forests. The species had a larger average diameter and made a greater contribution to basal area than any species of the current live tree association. Results of the studies reported here support data from Hedman et al. (1996), who quantified the importance of chestnut as a major contributor of large woody debris to southern Appalachian streams. If chestnut comprises a large portion of a stream's large woody debris, the species must have been an important component of lower slopes in cove forests.

The demise of the chestnut has been implicated in the spread of rhododendron thickets (Woods and Shanks 1959, Clinton et al. 1994, Clinton and Vose 1996). Our results support this contention and also indicate that logging disturbance encourages the spread of rhododendron even more, as suggested by McGee and Smith (1967). Following the blight, the two unlogged, old-growth sites succeeded to an oak association dominated by white oak (*Quercus alba*), chestnut oak (*Q. prinus*), and Northern red oak, with a strong component of black birch and Eastern hemlock. The dominance of oak species on the two old-growth sites suggests that periodic fire had occurred in these stands prior to the blight, which allowed oaks to dominate the advance regeneration (Brose and Van Lear 1998, Brose and others 1999) and control rhododendron (Van Lear and Waldrop 1989, Van Lear 2000).

Logged sites succeeded toward a mixed mesophytic forest type dominated by yellow-poplar, Eastern hemlock, red maple, and black birch, with a small component of oaks and hickory. Logging disturbance, which provides a mineral soil seedbed and greater insolation, would be expected to favor pioneer species like yellow-poplar and black birch. Large canopy gaps (0.04 hectare and larger) are thought necessary for abundant regeneration of yellow-poplar (Busing 1993, 1995). Apparently, the deaths of individual chestnut trees in the two old-growth areas did not create gaps large enough for abundant yellow-poplar regeneration.

Rhododendron has replaced American chestnut as the ecological dominant in many cove forests of the southern Appalachians (Vandermast and Van Lear 2001). Following the chestnut blight, logging, and fire exclusion early in the last century, rhododendron has expanded far upslope and now tends to direct forest succession and development by affecting establishment and growth of advance regeneration and seedlings. With the exception of Eastern hemlock, no other woody species appeared to have the ability to attain overstory status on these study sites, although Phillips and Murdy (1985) and Clinton and Vose (1998) noted that red maple could regenerate and become established on some sites dominated by rhododendron. Herbaceous species richness declined markedly with increases in density of rhododendron thickets and after decades of rhododendron dominance may now be lost from certain sites in these riparian/cove forests.

The diversity of cove forests of the southern Appalachians is thought to be maintained through gap-phase disturbances (Barden 1981, Runkle 1982, Busing 1993). However, canopy gaps with medium density rhododendron thickets in the understory had no hardwood species in the midstory strata. Only Eastern hemlock was present in the midstory, indicating that most hardwood species will fail to become members of the overstory canopy.

Succession in rhododendron thickets appears to fit the Inhibition Pathway model proposed bv Connel and Slatyer (1977). In this model, certain plant species modify their environment so that recruitment of both early and late successional species is inhibited as long as current vegetation remains intact. Rhododendron dominates the regeneration layer and prevents successful recruitment of other species into other canopy strata because of its dense shade, acidic litter (Boettcher and Kalisz 1990) and possible allelopathic effects (Rice 1979, Nielsen et al. 1999). Without major disturbance, rhododendron will apparently occupy these sites indefinitely.

CONCLUSIONS

As overstories of southern Appalachian forests recovered from heavy logging, chestnut blight, and fire exclusion of the past century, rhododendron became the dominant understory component in many cove forests of the region. Rhododendron now poses a major threat to the sustained diversity and productivity of many cove forests. Recent research provides convincing evidence that expansion of rhododendron thickets has a detrimental effect on regeneration of high quality hardwood species, as well as adverse effects on the richness of the herbaceous layer. Canopy gaps created by various types of disturbances are not regenerating to hardwoods but are becoming denser and taller thickets of rhododendron. On some sites, successional trends indicate that thickets of this dense ericaceous shrub will become the climax vegetation.

Forest managers must find new methods to manage the hardwood resource in this region. A hands-off approach until final harvest will not regenerate diverse and productive hardwood forests on cove sites where rhododendron has become estabished. Ways to control the spread and reduce the biomass of rhododendron tickets must be found. Greater efforts are needed to understand community dynamics in Southern Appalachian cove forests and to learn how to direct successional patterns.

ACKNOWLEDGMENTS

We would like to acknowledge the assistance of Peter R. Kapeluck and Wayne D. Carroll, Research Foresters in the Department of Forest Resources, Clemson University, in many phases of these studies. We also appreciate financial assistance from McIntire-Stennis and the U.S. Forest Service.

REFERENCES

Abrams, M.D.; D.M. McCay. 1996. Vegetation-site relationships of witness trees (1780-1856) in the pre-settlement forests of eastern West Virginia. Canadian Journal of Forest Research. 26: 217-224.

Abrams, M.D.; C.M. Ruffner. 1995. Physiographic analysis of witness-tree distribution (1765-1789) and present forest cover through north central Pennsylvania. Canadian Journal of Forest Research. 25: 659-668.

Ayres, H.B.; W.W. Ashe. 1902. Description of the southern Appalachian forests, by river basins. Message from the President of the United States transmitting report of the Secretary of Agriculture in relation to the forests, rivers and mountains of the southern Appalachians. Appendix A. 192 p.

Baker, T.T.; D.H. Van Lear. 1998. Relations between density of rhododendron thickets and diversity of riparian forests. Forest Ecology and Management 109: 21-32.

Barden, L.S. 1981. Forest development in canopy gaps of a diverse hardwood forest of the southern Appalachian Mountains. Oikos 37: 205-209.

Barden, L.S. 1997. Historic prairies in the Piedmont of North and South Carolina, USA. Natural Areas Journal. 17: 149-152.

Boettcher, S.E.; P.J. Kalisz. 1990. Single-tree influence on soil properties in the mountains of eastern Kentucky. Ecology. 71: 1365-1372.

Brose, P.T.; D.H. Van Lear. 1998. Responses of hardwood advance regeneration to seasonal prescribed fires in oak-dominated shelterwood stands. Canadian Journal of Forest Research. 28: 331-339 p.

Brose, P.T.; D.H. Van Lear; P.D. Keyser. 1999. A shelterwood-burn technique for regenerating productive upland oak sites in the Piedmont region. Southern Journal of Applied Forestry. 23: 158-163.

Busing, R.T. 1993. Three decades of change at Albright Grove, Tennessee. Castanea. 58: 231-242.

Busing, R.T. 1995. Disturbance and the population dynamics of *Liriodendron tulipifera*: simulations with a spatial model of forest succession. Journal of Ecology. 83: 45-53.

Clinton, D.B.; L.R. Boring; W.T. Swank. 1994. Regeneration patterns in canopy gaps of mixed-oak forests of the Southern Appalachians: Influences of topographic positioned evergreen understory. American Midland Naturalist. l32: 308-319.

Clinton, B.D; J.M. Vose. 1996. Effects of *Rhododendron maximum* L. on *Acer rubrum* seedling establishment. Castanea. 61: 38-45.

Connell, J.H.; R.O. Slatyer. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. American Naturalist. 111: 1119-1144.

Delcourt, H.R.; P.A. Delcourt. 1997. Pre-Columbian native American use of fire on Southern Appalachian landscapes. Conservation Biology. 11: 1010-1014.

Hedman, C.W.; D.H. Van Lear. 1994. Structure and composition of Southern Appalachian riparian forests. Bulletin Torrey Botanical Club. 122: 134-144.

Hedman, C.W.; D.H. Van Lear; and W.T. Swank. 1996. In-stream large woody debris loading and riparian forest seral stage associations in the southern Appalachian Mountains. Canadian Journal of Forest Research. 26: 1218-1227.

Hill, M.O. 1979. TWINSPAN: A FORTRAN program arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ithaca, NY: Cornell University Department of Ecology and Systematics.

Keever, C. 1953. Present composition of some stands of the former oak-chestnut forest in the southern Blue Ridge Mountains. Ecology 34: 44-55.

Lorimer, C.G. 1980. Age structure and disturbance history of a southern Appalachian virgin forest. Ecology 61: 1169-1184.

McCarthy, B.C.; D.R. Bailey. 1996. Composition, structure and disturbance history ofCrabtree Woods: an old-growth forest of western Maryland. Bulletin of the Torrey Botanical Club. 123: 350-365.

McGee, C.E.; R.C. Smith. 1967. Undisturbed rhododendron thickets are not spreading. Journal of Forestry. 65: 334-336.

Monk, C.D.; D.T. McGinty; F.P. Day, Jr. 1985. The ecological importance of *Kalmia latifolia* and *Rhododendron maximum* in the deciduous forest of the southern Appalachians. Bulletin of the Torrey Botanical Club. 112: 187-193.

Neilsen, E.T., J.F. Walker, O.K. Miller, S.W. Semones, T.T. Lei, and B.D. Clinton. 1999.Inhibition of seedling survival under *Rhododendron maximum* (Ericaceae): Could allelopathybe a cause? American Journal of Botany. 86: 1597-1612.

Nelson, T.C. 1955. Chestnut replacement in the southern highlands. Ecology. 36: 352-353.

Parker, G.G., S.M. Hill, and L.A. Kuehnel. 1993. Decline of understory American chestnut (*Castanea dentata*) in a southern Appalachian forest. Canadian Journal of Forest Research. 23: 259-265.

Phillips, D.L. and W.H. Murdy. 1985. Effects of rhododendron (*Rhododendron maximum* L.) on regeneration in southern Appalachian hardwoods. Forest Science. 31: 226-233.

Rice, E.L. 1979. Allelopathy, an update. Botanical Review. 45: 15-109.

Rivers, C.T., D.H. Van Lear, B.D. Clinton, and T.A. Waldrop. 2000. Community composition in canopy gaps as influenced by presence or absence of *Rhododendron maximum*. In: Haywood, J.D., ed. Proceedings of the Tenth biennial southern silvicultural research conference; 1999 February 16-18, Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 57-60.

Runkle, J.R. 1982. Patterns of disturbance in some old-growth mesic forests of eastern North America. Ecology 63: 1533-1546.

Runkle, J.R. 1985. Disturbance regimes in temperate forests. The Ecology of Natural Disturbance and Patch Dynamics. S.T.A. Pickett ;P.S. White, eds. New York: Academic Press: 17-33.

SAS Institute, Inc. 1987. SAS/STAT guide for personal computers, 6th ed. SAS Institute, Inc.,Gary, NC.

Vandermast, D.B.; D.H. Van Lear. (In press). Riparian forest recovery in the southern Appalachians following the chestnut blight. Forest Ecology and Management.

Van Lear, D.H.; T.A. Waldrop. 1989. History, uses, and effects of fire in the Appalachians. USDA Forest Service, Southeastern Forest Experiment Station, General Technical Report SE-54. 20p.

Waldrop, T.A., ed. 1989. Proceedings of pine-hardwood mixtures: a symposium on management and ecology of the type; 1989 April 18-19; Atlanta, GA. Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 271p.

Whitaker, R.H. 1956. Vegetation of the Great Smoky Mountains. Ecological Monographs. 26: l-80.

Woods, F.W.; R.E. Shanks. 1959. Natural replacement of chestnut by other species in the Great Smoky Mountains National Park. Ecology. 40: 349-361.

Hardwood Nutrition

Moderator:

DAVID MOORHEAD
University of Georgia

EFFECT OF NITROGEN AND PHOSPHORUS FERTILIZATION ON GROWTH OF A SWEETGUM PLANTATION DAMAGED BY AN ICE STORM

Yanfei Guo and Curtis Vanderschaaf[1]

Abstract—In 1994, an ice storm impacted a 19-year-old sweetgum plantation (*Liquidambar styraciflua* L.) fertilized with nitrogen (N) and phosphorus (P) at age 4. Thirty-nine percent of the stems were broken, 55 percent were not damaged, and 6 percent were leaning. After the ice storm, differences in height and dbh among the fertilization treatments disappeared. To test if fertilization can increase growth of both damaged and undamaged trees, we applied N and P fertilizers in early 1999. Two fertilizers, ammonia nitrate and superphosphate, were used in four combinations of treatments: N only (205 lb. N/ac), P only (123 lb. P/ac), N+P (205 lb. N/ac + 123 lb. P/ac), and a control. The treatments were on the same plots that were treated at age 4. After one growing season, N increased overall dbh growth, and P increased height growth. The effect of P was mostly on the damaged trees with height growths of 5.8 feet for P only, and 6.5 feet for the N+P treatment, compared to 4.8 and 5.1 feet for N only and the control, respectively. P had been shown to increase height growth with N at age 11.

INTRODUCTION

Sweetgum (*Liquidambar styraciflua* L.) was one of the hardwood species that was used to meet demand for fiber in the 1970s. Fertilization was used to increase sweetgum productivity on less fertile sites, such as Coastal Plain soils. This study was established in 1975 to test the effect of nitrogen (N) and phosphorus (P) fertilization on growth of sweetgum seedlings. After one growing season, N fertilization increased both total height and diameter of the 4-year-old plantation (Ku and others 1981). The gain in height and diameter was maintained for many years. When last reported (Guo and others 1998), the 15-year-old trees treated with N fertilization averaged about 5.5 inches in dbh, which was significantly greater than those without N fertilization. Height was also greater for the trees treated with N only, but N+P fertilization further increased height growth at age 14. The effect of N on sweetgum growth has been previously studied in the southern United States (Berry 1987, Broadfoot 1966, Buckner and Maki 1977, Ku and others 1981, Nelson and Switzer 1990, Nelson and others 1995a). These studies revealed that fertilization, especially with N, improved sweetgum growth on soils ranging from fertile alluvial soils to less fertile Coastal Plain soils. Significant growth improvement with fertilization even occurred in a 20-year-old sweetgum stand (Broadfoot 1966). As for P fertilization, Nelson and Switzer (1990) found in a preliminary greenhouse study that sweetgum responded to P fertilization, but that P did not increase growth in a field study. Broadfoot (1966) reported greater height growth of a 20-year-old sweetgum following a N+P+potassium (K) application.

On February 10, 1994, an ice storm struck southeastern Arkansas and caused considerable damage to the sweetgum plantation. Overall, trees with stem breakage averaged 39 percent, compared to 55 percent with no damage, and 6 percent leaning. Percentage of breakage did not differ statistically among fertilization treatments (Guo 1999). After the ice storm, differences in height and dbh among the fertilization treatments disappeared. To test whether fertilization can increase growth of both damaged and undamaged trees, we applied fertilizers to the plantation. The objective was to determine the effect of N and P fertilization on height and dbh growth of damaged and undamaged 25-year-old sweetgum trees.

METHODS AND PROCEDURES

The study was located in Drew County, AR (91° 46' W and 33° 37' 31" N) in the West Gulf Coastal Plain physiographic province. The soil is a poorly-drained Henry silt loam (Typic Fragiaqualf) and was formed from wind-blown silt. The native vegetation is mixed pines and hardwoods. A representative soil profile includes a surface 28-in. thick, light-gray to gray mottled silt loam, a 25-in. thick subsoil of firm, brittle fragipan (light-brownish gray, mottled silt clay loam), and mottled silt loam beneath to a depth of 72 inches. The natural fertility is moderate and the site index for sweetgum is 80 feet at age 50 (Larance and others 1976). The climate is subtropical humid with an average annual rainfall of 53 inches per year. Rainfall is somewhat greater in the winter and early spring, and summers may include drought periods.

[1] Graduate Student, Professor, Arkansas Forest Resources Center, School of Forest Resources, University of Arkansas at Monticello, Monticello, AR, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

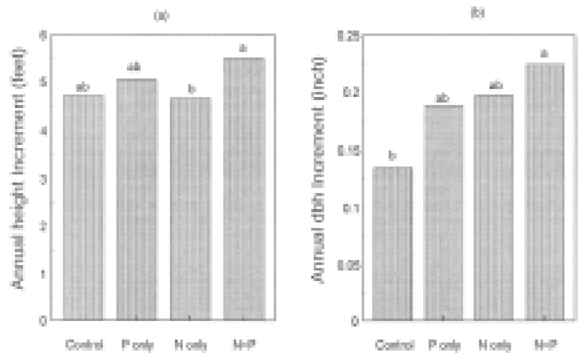


Figure 1—Effect of nitrogen and phosphorus fertilization on overall height (a) and dbh (b) increments one growing season after fertilization. Bars with the same letter are not significantly different at $\alpha = 0.05$.

The study was established in 1975 with 1-year-old seedlings (1-0 stock) planted at a spacing of 9 x 9 feet. Two fertilizers, ammonium nitrate and superphosphate, were applied in 1979 with an experimental design of 2 x 2 factorial in a completely randomized block layout with six blocks. The four combinations of treatments were N only at a rate of 205 lb. N/ac of ammonium nitrate (N only), P only at 123 lb. P/ac of superphosphate (P only), N and P at 205 lb. N/ac + 123 lb. P/ac (N+P), and no N or P [control (C)]. Each plot contained 50 trees (537 trees/ac), with 10 trees in each of five rows. The first and last row and the first tree and last tree of each row served as border trees to isolate the effects of adjacent plots. Measurements were obtained from the interior 24 trees. The survival rate was from 62 to 73 percent at age 15, but did not differ significantly among treatments. The ice storm did not affect the survival. In the spring of 1999, five growing seasons after the ice storm, plots were treated with the same rates of N and P that were used in 1979. Granular fertilizers were applied on the soil surface by hand. Height and dbh were measured just before the fertilization. Total height and dbh did not differ significantly prior to the treatments. After one growing season of fertilization, height and dbh were measured in January 2000.

Annual increments in height and dbh were analyzed by General Linear Models of SAS (SAS Institute, Inc., 1990). The data analysis was based on a split plot model with fertilization as the major plot and ice damage as the subplot. The subplot had two levels: damaged and undamaged. Leaning trees were considered undamaged trees. A small number of damaged trees (< 4percent on average per plot) did not show any growth, so these trees were not included in the data analysis. Means were separated by the Ryan-Einot-Gabriel-Welsch multiple range test at $\alpha = 0.05$.

RESULTS

Overall, P influenced height increments at p = 0.09, and N affected dbh increments at p = 0.08. There was no interaction between N and P (p = 0.81 for height and p = 0.56 for dbh). Height increments averaged 5.5 feet for the N+P treatment and 5.1 feet for the P only treatment, which were significantly greater than the 4.7 feet for the N only treatment. However, height increments for the N+P and P only treatments did not differ statistically from the control, while height increments among the P only, N only, and the control were not significantly different (figure 1a). For the dbh increment, N+P fertilization resulted in a growth of 0.22 inches, which was not statistically different from 0.20 inches for the N only and 0.19 inches for the P only treatments but significantly greater than the 0.14 inches for the control. (figure 1b).

Height growth of the damaged trees was significantly greater than the undamaged trees. Damaged trees

Table 1—Mean annual height and diameter increments of damaged and undamaged trees and their associated standard errors of an ice-storm damaged sweetgum plantation one growing season after fertilization with nitrogen and phosphorus

	Damaged		Undamaged	
Treatment	Mean	Standard Error	Mean	Standard Error
	------------------------*Height Increment (feet)*------------------------			
Control	5.07	0.37	4.35	0.40
P only	5.81	0.32	4.31	0.49
N only	4.76	0.42	4.55	0.38
N+P	6.47	0.44	4.55	0.37
	------------------------*Dbh Increment (inch)*---------------------------			
Control	0.08	0.08	0.20	0.08
P only	0.14	0.12	0.23	0.13
N only	0.16	0.11	0.23	0.15
N+P	0.18	0.09	0.27	0.15

averaged 5.5 feet during the growing season after the fertilization while undamaged trees averaged 4.4 feet. Dbh growth was opposite. Dbh growth was 0.23 inches for the undamaged trees, which was significantly greater than the 0.14 inches growth for the damaged trees.

The difference in height growth among the treatments was likely caused by the effect of the P fertilization on damaged trees (table 1). The height increments were 5.81 and 6.47 feet for the P only and N+P treatments, respectively, which were greater than those (5.07 and 4.76 feet) for the control and N only treatments. Height growth of the undamaged trees was similar among the treatments. The pattern of the dbh increments among the treatments for the damaged trees was similar to that of the overall increments, except that dbh increments were smaller for the damaged trees than the overall means (table 1).

DISCUSSION

N fertilization did not affect height growth of both damaged and undamaged trees, but P affected height growth in this study. Broadfoot (1966) found height increases for a 22-year-old sweetgum stand fertilized with N+P+K. However, it was not clear whether N alone increased the height growth in the study. P was not found to increase height growth in other studies for young stands (Berry 1987, Buckner and Maki 1977, Nelson and others 1995a), including the stand of this study in early ages. However, at age 14, P along with N was found to increase height growth significantly (Guo and others 1998). This phenomenon probably resulted from an increased demand of P by the faster-growing trees. P did not affect height growth of the young sweetgum stands because demand for P was relatively low. As demand of large trees increased, especially the trees with greater height, additional P in the soil promoted height growth. It seems that accelerated height growth of larger trees requires more P to maintain the increased height growth rates, this seems evident from the results of Broadfoot (1966), Guo and others (1998), and this current study.

The response of height growth to P in this study was complicated by the ice storm damage. Since the ice storm, height growth of the damaged trees has been significantly greater than that of the undamaged trees, although there have been no significant differences among the fertilization treatments. Increased height growth of ice storm damaged trees was also observed by Dunham and Bourgeois (1996). They attributed this phenomenon to the fact that most damaged trees were initially dominant or codominant trees, and rapid height growth was to recapture the lost crown position. The sweetgum trees in this study acted similarly to those of Dunham and Bourgeois (1996). Since larger sweetgum trees, compared to surrounding trees, have a greater probability to be broken (Guo 1999), most damaged trees were dominant and codominant trees. Compared to the damaged trees, undamaged trees had greater dbh growth but relatively slower height growth, although the height growth was also fairly fast (> 4 feet during the growing season of 1999, which was faster than a 3-foot average height growth for sweetgum). It seems that P further increased height growth of the damaged trees because they needed greater height growth to recapture their crown positions. This demand required additional P from the soils. Without the additional P, height growth potential was limited.

A related phenomenon to the greater height growth of the damaged trees was their reduced dbh growth compared to the undamaged trees. It seems that P does not affect dbh growth of sweetgum and N is more important than P for dbh growth. With accelerated height growth, the damaged trees had to allocate more resources for height growth. Dbh growth was then slowed.

Overall, the average heights of the undamaged and damaged trees were 57.8 and 50.2 feet, respectively, at age 25. The site index for the undamaged trees was slightly greater than the 80-foot site index at age 50, which is about 55 feet at age 25, based on the site index curves developed by Clatterbuck (1987) for central Mississippi minor bottoms. This site index of the undamaged trees is greater than that measured two years after the ice storm or three years before this measurement. The site index of the undamaged trees was below 80 feet at age 50 then. Three years later, site indexes have increased to about 85 feet. This phenomenon suggests that the undamaged trees have been growing faster after the ice storm than before it. The ice storm resulted in the undamaged trees switching from being less dominant to dominant or codominant trees, and they have been growing with a faster-than-average height growth rate in the last five years. On the other hand, although the damaged trees have been growing faster than the undamaged trees in height, they still have an additional 7-8 feet to grow before they catch up.

CONCLUSION

Phosphorus fertilization at age 24 increased overall height growth of the sweetgum plantation, but the effect was mostly on the damaged trees. Nitrogen fertilization helped dbh growth, but not the height growth. Damaged trees had greater height growth but smaller dbh growth than the undamaged trees.

REFERENCES

Berry, C.R. 1987. Use of municipal sewage sludge for improvement of forest sites in the southeast. Asheville, NC: U.S. Department of Agriculture, Forest Service Res. Pap. SE-266, Southeastern Forest Experiment Station. 33 p.

Broadfoot, W.M. 1966. Five years of nitrogen fertilization in a sweetgum-oak stand. USDA Forest Service Research Note SO-34. 3 p.

Buckner, E.; T.E. Maki. 1977. Seven-year growth of fertilized and irrigated yellow poplar, sweetgum, northern red oak, and loblolly pine planted on two sites. Forest Science. 23: 402-410.

Clatterbuck, W.K. 1987. Height growth and site index curves for cherrybark oak and sweetgum in mixed, even-aged stands on the minor bottoms of central Mississippi. Southern Journal of Applied Forestry 11(4): 219-222.

Dunham, P. H.; D. M. Bourgeois. 1996. Long-term recovery of plantation-grown loblolly pine from hurricane damage. In: J. L. Haymond and W. R. Harms. Eds. 1996. Hurricane Hugo: South Carolina forested land research and management related to the storm. Gen. Tech. Rep. SRS-5. Asheville, NC. U.S.Department of Agriculture, Forest Service. 480-490 p.

Guo, Y. 1999. Ice storm damage to a sweetgum plantation fertilized with nitrogen and phosphorus. Southern Journal of Applied Forestry. 23(4): 224-229.

Guo, Y.; T. Ku; B. Lockhart. 1998. Effect of nitrogen and phosphorus fertilization on growth in a sweetgum plantation in southeastern Arkansas. Southern. Journal of Applied Forestry. 22(3): 163-168.

Ku, T.T.; J.K. Francis; C.R. Blinn. 1981. Fertilizer response and biomass accumulation of a five-year-old sweetgum plantation. In: Barnett, J.P., ed. Proceedings of the First biennial southern silvicultural research conference; 1980 November 6-7, Atlanta, GA. Gen. Tech. Rep. SO-34. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 195-198.

Larance, F.; H.V. Gill; C.L. Fultz. 1976. Soil survey of Drew County, Arkansas. U.S. Department of Agriculture Soil Conservation Service. 86 p.

Nelson, L.E.; M.G. Shelton; G.L. Switzer. 1995a. Aboveground net primary productivity and nutrient content of fertilized plantation sweetgum. Soil Science Society American Journal. 59: 925-932.

Nelson, L.E.; G.L. Switzer. 1990. Sweetgum half-sib seed source response to nitrogen and phosphorus fertilization in Mississippi. Soil Science Society American Journal. 54: 871-878.

SAS Institute, Inc., 1990. SAS User's Guide, Version 6, 4th Edition. SAS Institute, Inc., Vol. 2. Cary, NC. 846 p.

SWEETGUM RESPONSE TO NITROGEN FERTILIZATION ON SITES OF DIFFERENT QUALITY AND LAND USE HISTORY

D. Andrew Scott, Donald J. Kaczmarek, James A. Burger, and Michael B. Kane[1]

Abstract—Nitrogen (N) fertilizer management in young hardwood plantations is difficult due to our lack of understanding of the site-specific mechanisms that control tree response. Differences in landuse history and soil characteristics can alter the plant response to added N considerably. Foliage biomass, N content, N concentration, resorption, and soil N supply characteristics were measured on two 4 year-old sweetgum (*Liquidambar styraciflua* L.) plantations in South Carolina that represent different landuse histories and soil types. Fertilizer responses were much greater overall on a poorly drained pine cutover site compared to a well-drained ag field. Vector analysis and analysis of variance indicated that fertilization increased foliage biomass, N content, N concentration, and leaf area on the cutover site, but only increased foliar N content on the ag site. Foliar responses were negatively related to actual soil N supply, but not potentially mineralizable or total N. N fertilizer recommendations must be site-specific, and an accurate estimate of soil N supply is essential for increasing fertilization efficiency.

INTRODUCTION

Sweetgum and other hardwood plantations have the potential to be an important source of hardwood fiber throughout the South, but the success of hardwood plantations depends heavily on management intensity. Relative to loblolly pine plantations, sweetgum plantations require more intensive site selection and preparation, herbaceous and woody competition control, and nutrient management for plantation success.

Abandoned or marginal agricultural fields have historically been the primary lands planted to hardwood plantations throughout the South, but the demand and value of hardwood fiber coupled with the relative paucity of agricultural lands in certain local areas has increased the area of cutover pine lands planted to hardwood plantations. Within these two groupings of potential hardwood plantation lands, wide differences exist in soil types, which makes our understanding of site-specific plantation responses to various treatments difficult.

Specifically, accurate, site-specific hardwood nitrogen (N) fertilizer recommendations are not yet available for hardwood plantations because of our lack of understanding of the site-specific influences on soil N supply, plant N demand, and plant response to various fertilizer rates. Several studies have shown the impressive response of young hardwood stands to N fertilizer, but variations in soil types, fertilizer rates, and management differences have hindered our ability to make accurate N fertilizer recommendations.

In most studies, N fertilization has resulted in growth responses. A few studies have linked N fertilization response to soil type or previous management (Torreano and Frederick, 1988), illustrating that the soil N supply can control the response to added N. For example, Wittwer and others (1980) applied N fertilizer each year to sycamore (*Platanus occidentalis* L.) on a bottomland site and on a terrace site. They observed a 45 percent growth response on the bottomland site and a 205 percent growth response on the terrace site at age 5, and attributed the relative response to soil N. Torreano and Frederick (1988) and Blackmon (1977) showed that hardwoods may respond quite differently on pine cutover sites than on abandoned agricultural sites.

Most recently, studies have focused on determining fertilization effects on specific plant responses other than height or volume growth. Since approximately 50 percent of aboveground plant N uptake is met by resorption of foliar N prior to senescence (Aerts and Chapin, 2000), factors which affect the resorption efficiency may dramatically change fertilizer needs. Nelson and others (1995) reported resorption efficiencies of 50-74 percent for sweetgum and attributed differences to environmental conditions, i.e., moisture availability, but not N fertilization. Kuers and Steinbeck (1998a) found similar efficiencies of 43-62 percent for sweetgum, but reported significant increases in resorption efficiency in the fertilized treatment.

[1]Graduate Research Assistant, Department of Forestry, Virginia Tech, Blacksburg, VA 24060; Forest Nutrition Scientist, Westvaco Forest Science and Technology, Summerville, SC 29484; Professor of Forest Soils, Department of Forestry, Virginia Tech, Blacksburg, VA 24060; Research Scientist, International Paper Corporation, Prattville, AL 36067, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

To better understand the processes controlling sweetgum response to added N, the objectives of this study were to quantify the foliar response to N fertilizer treatments on two contrasting site types and relate potential differences in foliar responses to soil N supply parameters.

METHODS

Site Descriptions and Characterization

The pine cutover site is on Westvaco Corporation land, located in Colleton County, South Carolina (32° 8' N 80° 7' W) on the lower Atlantic coastal plain, and was established in February 1995. The soil is a somewhat poorly to poorly drained Argent sandy loam (clayey, mixed, active, Typic Endoaqualfs) developed from marine deposits. The site undergoes wide fluctuations in soil water contents, from saturated soils with standing water in the bed furrows in the late fall until spring to dry soils during the growing season. Nine 0.2 ha sweetgum plots were established following loblolly pine harvest and site preparation, which consisted of bedding, fertilization and non-crop vegetation control. All plots received 280 kg/ha diammonium phosphate (DAP) in March 1995. Non-crop vegetation control consisted of pre-emergent herbicide applications in February and March of 1995, 1996, and 1997. Herbicides were also applied by directed spray in 1995 and 1996 during the growing season.

The agricultural field study site is located on International Paper's Trice Research Forest in Sumter County, South Carolina (33° 58' N 80° 12' W) on the middle Atlantic coastal plain. The soil is a well-drained Norfolk sandy loam (loamy, kaolinitic, thermic Typic Kandiudult. Nine 0.2 ha sweetgum plots were established in 1996. The sites had been regularly managed for dryland crops (corn, soybeans, etc.) for more than 20 years, and soybeans (*Glycine max.* (L.) Merr) were the primary crop for the 5 years previous to woody crop plantation conversion. All plots were treated with an initial fertilizer program of 280 kg/ha diammonium phosphate (DAP) in November 1995 and 101 kg/ha urea in August 1996.

Experimental Design

At each site, three biannual N fertilizer treatments were initiated at age 1 and replicated three times. Every two years, ammonium nitrate (NH^4NO^3) was applied at the following rates: 0 kg/ha, 168 kg/ha, and 336 kg/ha, which provide 0, 56, and 112 kg/ha N, respectively. The error control design at the cutover site was a Completely Randomized Design, while the design at the agricultural site was a Randomized Complete Block Design. The blocking factor was depth to mottling.

Table 1—Proportion of total foliage dry mass in each of three crown positions by fertilizer treatment, after Kuers and Steinbeck, 1998b

Crown	Control	Low N	High N
Upper	0.35	0.35	0.35
Middle	0.38	0.41	0.44
Crown	0.27	0.24	0.21

Foliage Measurements

In September 1998 (pine cutover site) and 1999 (ag field), which corresponded to age 4 in both plantations, 3 foliage samples were taken from the southern portion of the canopy from five trees in each plot. Upper, middle, and lower crown samples comprised of leaves of all stages of development were collected from single branches within the respective crown position (Kuers and Steinbeck, 1998b). The leaves were refrigerated until leaf area determinations were made with a Li-Cor Leaf Area Meter (Li-Cor, Lincoln, NE). The leaves were then oven dried at 65 °C for at least 72 hours and weighed to determine specific leaf area (cm^2/g). Foliar N concentration was determined on each sample with a N analyzer (LECO FP-528, St. Joseph, MI) and converted to total nutrient content with estimates of foliage mass obtained from litterfall measurements. Litterfall was collected from 5 randomly located litter traps (approximately 1 m^2 per trap) per plot.

Kuers and Steinbeck (1998b) showed that fertilization increases sweetgum leaf area disproportionately between the leader, upper, middle, and lower crown positions. If the leader is included with the upper crown, they found 35, 37, and 27 percent of the total dry mass in the upper, middle, and lower crowns positions, respectively. However, in plots fertilized at a higher rate of N than the highest rate in this proposed study, they found 36, 44, and 21 percent of total dry mass in the upper, middle, and lower crown positions, respectively. We calculated total foliar nutrient demand as the summation of the products of foliar nutrient concentration and estimated foliage mass for each crown position (table 1). Foliar N resorption was calculated as the difference between foliar N content at midseason and in the litterfall (Nelson and others, 1995).

Soil Nitrogen Supply

Total nitrogen—Total N was determined on a 5 g soil sample using the macro-Kjeldahl digestion method (Bremner and Mulvaney, 1982) followed by colorimetric analysis (Bran+Luebbe TRAACS 2000, Oak Park, IL).

Potentially mineralizable nitrogen—Nitrogen mineralization potential was determined by measuring NH^{4+} and NO^{3-} produced in biweekly extractions of aerobically incubated soil samples for 24 weeks (Stanford and Smith, 1972; Burger and Pritchett, 1984). Briefly, approximately 70 g field-moist soil from each site was mixed with approximately 150 g washed silica sand and lightly packed into a 5 cm i.d. and 15 cm long PVC tube. The samples were incubated at 35 °C. Every two weeks, the samples were leached with 250 mL of 0.01 M CaCl2, which was analyzed for NH^{4+} and NO^{3-} concentration via automatic colorimetric spectrophotometry on a TRAACS 2000 (Bran & Luebbe Corporation, Oak Park, IL). The samples were then leached with 100 mL of a minus-N Hoagland solution and vacuum extracted to approximately -0.03 MPa (field capacity). N mineralization potential was calculated by fitting a first-order curve to the sequential N produced using PROC NLIN in SAS (SAS, 1990).

Table 2— Foliar biomass, weighted foliar N concentration and litter N concentration for two 4-year-old sweetgum plantations of different landuse history and soil type. Means within a site followed by the same letter are not significantly different at alpha=0.10

Treatment	Foliar Biomass kg/ha	Foliar N Concentration pct	Litter N Concentration pct
Ag field			
Control	2263a	1.37a	0.97a
56 kg/ha N	2475a	1.71a	0.97a
112 kg/ha N	3100a	1.69a	1.00a
Pine cutover			
Control	1337b	1.14c	0.63b
56 kg/ha N	1945ab	1.39b	0.73ab
112 kg/ha N	2825a	1.54a	0.76a

***In situ* nitrogen production—**Native soil N supply was measured from April 1999 to April 2000 with the buried bag method (Eno, 1960). For this procedure, two soil samples were collected for each sampling date. One was incubated in situ and the other returned to the laboratory for analysis. N supply was calculated as the difference between the N intensity in the soils incubated for approximately 1 month and the samples taken at the time of incubation, with negative values, representing net immobilization or denitrification, set to 0. At each of three subplots within each experimental plot, three subsamples were taken of the top 15 cm and composited for each of the two samples (bags). Each sample was air-dried, sieved to pass a 2 mm sieve, and the N extracted with 2 N KCl in a 10:1 solution:soil ratio. The NH4+ and NO3- concentration in each extract was determined via automatic colorimetric spectrophotometry on a TRAACS 2000 (Bran & Luebbe Corporation, Oak Park, IL).

Soil moisture—Volumetric soil moisture in the top 15 cm was measured monthly from April 1999 to September 2000 with Time Domain Reflectometry.

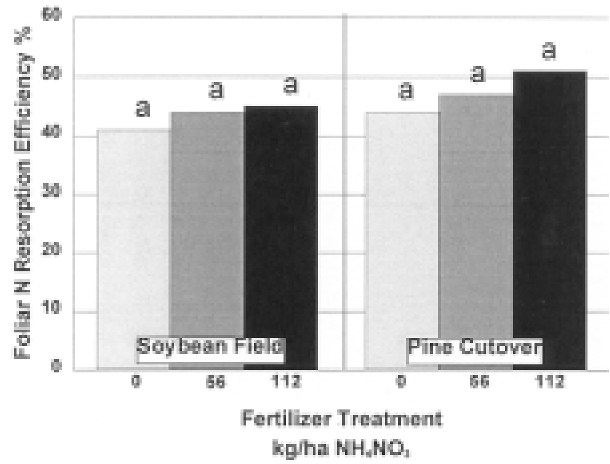


Figure 2—Foliar nitrogen resorption efficiency across three levels of N fertilization in two 4-year-old sweetgum stands of varying land use history and soil type. Means within a site type followed by the same letter are not significantly different at alpha=0.10.

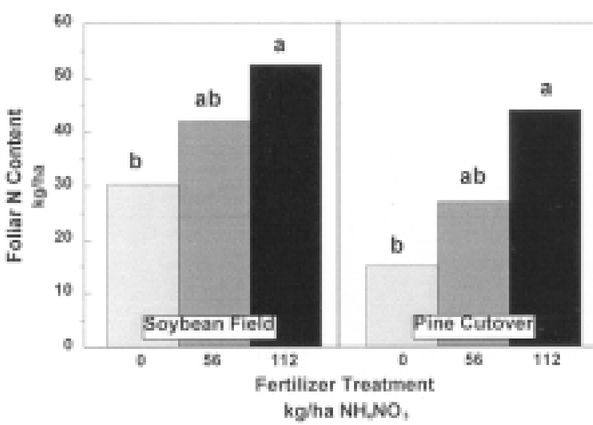


Figure 1—Foliar nitrogen content across three levels of N fertilization in two 4-year-old sweetgum stands of varying land use history and soil type. Means within a site type followed by the same letter are not significantly different at alpha=0.10.

RESULTS

Fertilization increased foliar biomass, N concentration, and N content at both sites, but the relative responses were greater on the pine cutover site. Foliar N content increased at both sites on fertilized plots (figure 1) due to increases in total foliage biomass and N concentrations (table 2). On the ag field, foliar N content of the 56 kg/ha N treatment was 40 percent higher than the control, while it was 73 percent higher than the control in the 112 kg/ha N treatment. In the cutover pine site, foliar N content increased 80 percent and 193 percent over the control in the medium and high treatments, respectively. Weighted foliar N concentrations ranged from 1.14 percent to 1.71 percent, and increased at both sites with fertilization.

Foliar resorption efficiency, which is calculated as the proportion of total foliar N resorbed, was not different among fertilization treatments, and the pine cutover site had greater resorption efficiency compared to the ag field site (figure 2). Foliar resorption proficiency, which is measured as the N concentration in the litterfall, was not

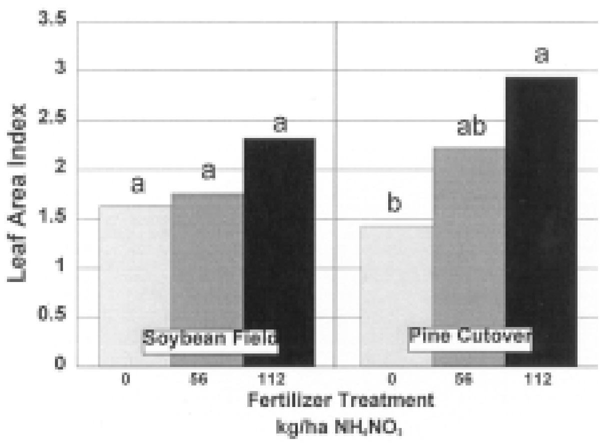


Figure 3—Leaf area index across three levels of N fertilization in two 4-year-old sweetgum stands of varying land use history and soil type. Means within a site type followed by the same letter are not significantly different at alpha=0.10.

affected by fertilization treatment at the ag field site. In the pine cutover site, resorption proficiency was greater than in the ag field site (litter N concentrations lower), and was significantly reduced (litter N concentrations higher) by the highest fertilization rate (table 2).

Leaf area index of trees on the ag field ranged from 1.6 to 2.3, but was not significantly affected by fertilization. LAI of the 112 kg/ha N treatment (3.0) was twice that of the control (1.5) in at the pine cutover site (figure 3). Plot volume index (PVI) did not differ among treatments on the ag field site (figure 4), and although not significantly different, PVI was 47 and 63 percent higher than the control in the 56 kg/ha and 112 kg/ha N treatments, respectively on the pine cutover site.

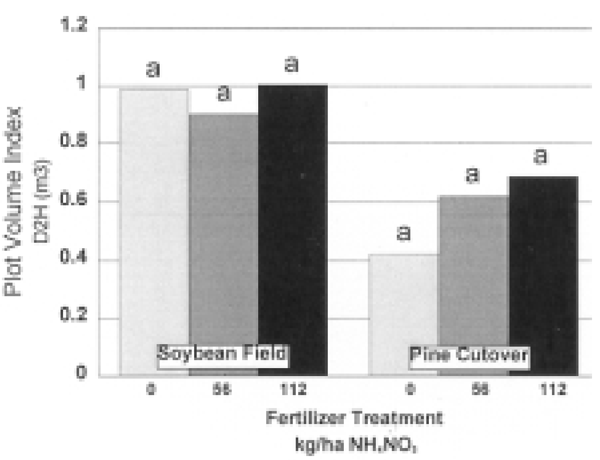


Figure 4—Plot volume index across three levels of N fertilization in two 4-year-old sweetgum stands of varying land use history and soil type. Means within a site type followed by the same letter are not significantly different at alpha=0.10.

Soil nitrogen differed widely between the sites and among indices (figure 5). Total soil N in the top 15 cm of the cutover pine site was 2.6 times higher than that of the ag field site, but the aerobic index of potentially mineralizable N was only 18 percent higher. Measured in situ N production was much less in the cutover pine site, averaging 72 percent less than in the ag field site.

Soil moisture varied seasonally and across both sites, but was consistently greater on the poorly-drained cutover site compared to the well-drained ag site (figure 6). Soil moisture averaged 9.7 percent on the ag site and was never greater than 20 percent, while soil moisture averaged 19.9 percent on the cutover site and was as high as 32 percent.

DISCUSSION

Foliar biomass production, N demand, and N resorption were each associated with site type and fertilizer treatments. Foliage production ranged from 1337 kg/ha to 3100 kg/ha, and foliar N content ranged from 15 to 53 kg/ha. Higher foliage biomass production, however, did not directly result in higher leaf areas (figure 3) nor tree growth (figure 4) in these young stands, but may in the future. Foliage production and foliar N content was greater overall at the ag field site compared to the pine cutover site, but fertilization responses were more dramatic on the cutover site. A host of factors may have contributed to these site differences, such as water availability and competition. The ag field site, although generally much drier than the pine cutover site, has virtually no competing woody vegetation, while the cutover site has substantially more woody competition.

Foliar N resorption efficiency was not significantly affected by fertilization, but tended to increase on the fertilized plots in both sites. These findings are in general agreement with Nelson and others (1995), who found no influence of fertilization on resorption efficiencies and Kuers and Steinbeck (1998), who observed an increase in resorption efficiency from 52.8 percent to 61.7 percent. The range of

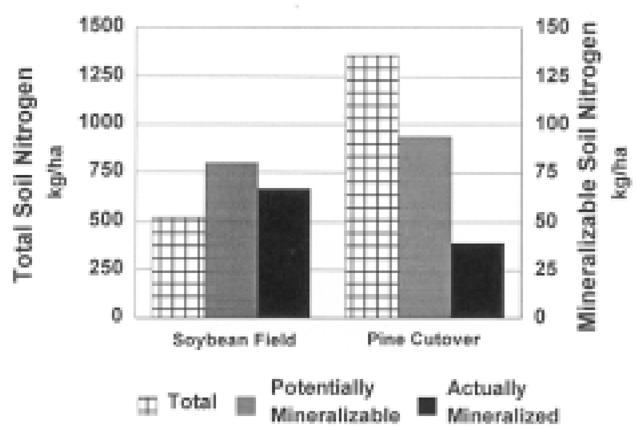


Figure 5—Total, potentially mineralizable, and actual soil N mineralized in two 4-year-old sweetgum stands of different land use history and soil type.

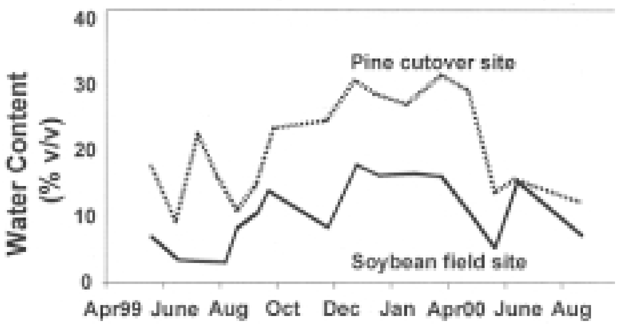


Figure 6—Volumetric soil water contents from April 1999 to September 2000 at two 4-year-old sweetgum stands of different land use history and soil type.

resorption efficiencies observed (41 percent to 52 percent) is low for sweetgum plantations. Resorption efficiency was higher on the cutover site than on the ag field site, indicating that factors other than nutrition, such as moisture availability, combined to control N resorption efficiency. del Arco and others (1991) found that resorption efficiency was lower on more xeric sites, suggesting that the drier soil of the ag field site may have reduced resorption efficiency.

Increases in foliar N content or concentration due to fertilization do not necessarily signify a foliar biomass response. Vector analysis (Krauss, 1965; Haase and Rose, 1995) was performed in this study using relative foliar N content, concentration, and foliage biomass for both sites (figure 7). In all cases except the 56 kg/ha N treatment on the ag field site, vector analysis indicated that the control plots were indeed deficient, and fertilization resulted in increases in foliar N content, concentration, and biomass. The length of the vectors gives an indication of the relative magnitude of the response to various treatments, and it is apparent from figure 6 that the response was much greater on the pine cutover site compared to the ag field site. The lower rate of fertilization on the ag cutover site was only enough to increase the foliar N content and concentration, but not cause an increase in foliar or tree biomass production relative to the control treatment.

Increasing foliar N concentrations can increase photosynthetic efficiency, but fertilizer applications in young stands are more useful as a means of increasing the total photosynthetic capacity through increased leaf area. In this study, the high rate of fertilization almost doubled the leaf area of the pine cutover stand, but fertilization had no significant effect on the ag field site. This indicates, like the vector analysis, that fertilization was much more effective on the pine cutover site compared to the ag field site.

Actual soil N supply, which would be predicted to be much higher at the pine cutover site due to its 6-fold greater soil organic matter (6 percent vs 1 percent), was almost half that of the ag field. Much more of the total organic N was in a recalcitrant form on the pine cutover site. Only 7 percent of the total soil N was potentially mineralizable on the cutover site, while 15 percent was potentially mineralizable on the ag field site. Furthermore, microbial immobilization and denitrification were likely much greater on the cutover site

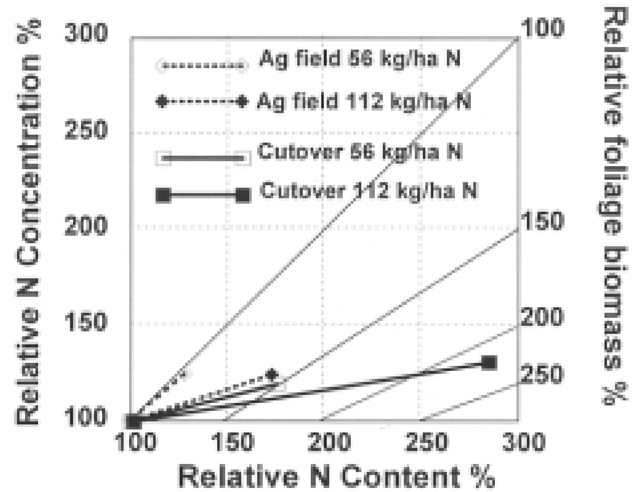


Figure 7—Vector analysis of relative responses in foliage biomass, N concentration, and N content in two 4-year-old sweetgum stands of varying land use history and soil type.

than at the ag site. The C:N ratio of the soil organic matter on the pine cutover site was 53, while only 28 at the ag site. Net immobilization is known to be greater as C:N ratios increase, and net N mineralization does not generally occur until the ratio is near 30. Preliminary findings from a related study indicate that fertilization may increase N mineralization on the pine cutover site. Denitrification may have been important on the cutover site due to wet but fluctuating moisture conditions (figure 6) and a high C energy source (Davidson and Swank 1987).

CONCLUSIONS

Developing efficient N management strategies for young sweetgum plantations and understanding plant responses to N fertilization requires an accurate estimate of actual soil N supply. This study showed that fertilizing young sweetgum plantations can result in large increases in foliar biomass, N content, and leaf area on some sites, but it may not be necessary on others. Simple estimates of soil N availability, such as organic matter content, total soil N, or even indices of potentially mineralizable N may not indicate the extent of plant response to N fertilizer; more accurate estimates of soil N availability that take environmental conditions into account as well are needed for developing N fertilizer recommendations for young hardwood plantations.

REFERENCES

Aerts, R.; F.S. Chapin III. 2000. The mineral nutrition of wild plants revisited: a re-evaluation of processes and patterns. Advances in Ecology Research 30: 1-67.

Blackmon, B. 1977. Cottonwood response to nitrogen related to plantation age and site. USDA Forest Service Southern Forest Experiment Statation Research Note SO-229: 3 p.

Bremner, J.M.; C.S. Mulvaney. 1982. Nitrogen - Total. p. 595-624. In: A.L. Page (ed.) Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, 2nd. Soil Science Society of America Publication No. 9. Part 2.

Burger, J.A.; W.L. Pritchett. 1984. Effects of clearfelling and site preparation on nitrogen mineralization in a southern pine stand. Soil Science Society American Journal 48: 1432-1437.

Davidson, E.; W. Swank. 1987. Factors limiting denitrification in soils from mature and disturbed southeastern hardwood forests. Forest Science 33: 135-144.

Eno, C.F. 1960. Nitrate production in the field by incubating the soil in polyethylene bags. Soil Science Society of America Proceedings 24: 277-279.

Guo, Y.; Lockhart, B.R.; T.T. Ku. 1998. Effect of nitrogen and phosphorus fertilization on growth in a sweetgum plantation in southeastern Arkansas. Southern Journal Applied Forestry 22: 163-168.

Haase, D.L.; R. Rose. 1995. Vector analysis and its use for interpreting plant nutrient shifts in response to silvicultural treatments. Forest Science 41: 54-66.

Krauss, H.H. 1965. Untersuchungenüber die Melioration degradierter Sandböden im nordostdeutschen Tiefland. Arch. Forstwes. 14:499-532.

Kuers, K.; K. Steinbeck. 1998a. Foliar nitrogen dynamics in Liquidambar styraciflua saplings: response to nitrogen fertilization. Canadian Journal Forest Research 28: 1671-1680.

Kuers, K.; K. Steinbeck. 1998b. Leaf area dynamics in Liquidambar styraciflua saplings: responses to nitrogen fertilization. Canadian Journal Forest Research 28: 1660-1670.

Nelson, L.E.; Shelton, M.G.; G.L. Switzer. 1995. The influence of nitrogen applications on the resorption of foliar nutrients in sweetgum. Canadian Journal Forest Research 25: 298-306.

SAS Institute. 1990. SAS/STAT User's Guide, Version 6 Edition. SAS Institute Inc., Cary, N. C.

Stanford, G.; S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Science Society America Proceeding 36: 465-472.

Torreano, S.J.; Frederick. 1988. Influence of site condition, fertilization and spacing on short rotation hardwood coppice and seedling yields. Biomass 16: 183-198.

Wittwer, R.F.; Immel, M.J.; F.R. Ellingsworth. 1980. Nutrient uptake in fertilized plantations of American sycamore. Soil Science Society America Journal. 44: 606-610.

THE EFFECTS OF HARVESTING ON LONG-TERM SOIL PRODUCTIVITY IN SOUTHERN INDIANA OAK-HICKORY FORESTS

Travis W. Idol, Phillip E. Pope, and Felix Ponder, Jr.[1]

Abstract—Timber harvesting has the potential to alter long-term soil productivity in a variety of forest ecosystems. We monitored the effects of harvesting on N cycling processes in upland oak-hickory forests of southern Indiana, using a chronosequence of stands ranging in age from 1 year to 100 years after harvest. N cycling pools and processes were monitored from 1995-1999. Results suggest that reestablishment of fine root biomass occurs long before recovery of leaf area. The forest floor increases in relative importance for nutrient cycling with stand age. Litter decomposition is similar among stand ages. Estimates of actual evapotranspiration were significantly correlated with N cycling at most stages of forest development. There is a balance of litter N inputs, N mineralization, and N uptake at all stages of stand regeneration except at maturity. At this stage, litter N inputs were generally lower than N mineralization and N uptake.

INTRODUCTION

Data from various studies on forest N cycling at different stages of stand development can be used to reach general conclusions about ecosystem integrity, stand regeneration and nutrition, and recovery of N cycling pools and processes. Organization of the data into a conceptual model of N balances is one approach that can be used to make these assessments.

Two of the keys to the development of N cycling models are 1) the identification of the major ecosystem N pools and the transfer rates among these pools, and 2) an understanding of the degree to which N cycling is governed by internal pools and processes and external environmental factors.

For temperate hardwood forests, soil inorganic N is the major pool from which N is taken up for plant growth and metabolism (Nadelhoffer and others 1984). Much of the N is derived from the decomposition of vegetative N demand and uptake (Gholz and others 1985, Hendrickson 1988, Crow and others 1991). This may lead to a net loss of ecosystem N. As regeneration proceeds, this may lead to N limitations and reduced long-term site productivity. Only by monitoring N cycling at different stages of forest development, though, can these inferences by confirmed.

MATERIALS AND METHODS

We monitored various aspects of N cycling across a 100-year chronosequence of upland oak-hickory forests in southern Indiana, USA. Vegetation and site characteristics are listed in table 1. All of the regenerating stands were clear-cut harvested and represent different stages of forest development from recently-harvested through maturity. Litter production, litter decomposition, N mineralization and nitrification, N uptake, and soil temperature, moisture, and actual evapotranspiration were monitored from 1995-1999, although not all measurements were made in all years.

The data were compiled into a conceptual model of nutrient cycling, and simple correlation analysis was used to discover the relative strength of internal and external controls over N cycling at different stages of forest development. The basic design of the N balance model is similar to the one presented by Aber and others (1991) for the nutrient cycling model VEGIE (figure 1).

In the conceptual models below, boxes represent ecosystem pools of N. Arrows between boxes represent transfer rates of N. Circles represent factors that influence N cycling pools and processes. Pool sizes and transfer rates are given in kg N ha/yr per yr. Values inside circles represent the strength of the correlation (R-value). Because annual rates of N cycling were of interest, the year 1998, in which data was collected from April-December, was used to make assessments of net N mineralization, net nitrification, N uptake, and soil microbial biomass N (SMBN). During 1997 and 1999, N cycling measurements were made during fewer months of the year, so these data were not considered to be representative of annual N cycling rates. Relationships between AET and SMBN, AET and net N mineralization, and between net N mineralization, nitrification, and N uptake, however, were all based on three-year cumulative data. Data for fine root mortality and litter pool size come from Idol and others (2000). Data for litterfall

[1]Post-Graduate Researcher, Dept. of Land, Air, & Water Resources, University of California-Davis, One Shields Ave., Davis, CA 95616; Professor, Dept. of Forestry & Natural Resources, Purdue University, 1159 Forestry Bldg, West Lafayette, IN 47907; Research Soil Scientist, USDA Forest Service, North Central Research Station, 208 Foster Hall, Chestnut St., Lincoln University, Jefferson City, MO 65102, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

and forest floor mass come from Idol and others (1998). Data for woody debris come from Idol and others (1999). A question mark (?) represents missing data in the model.

RESULTS AND DISCUSSION

80-100 Year-Old Stand

Figure 2 illustrates the N balance model for the mature, 80-100 year-old stand. This forest should be near steady-state N cycling as discussed by Attiwill and Adams (1993). Specifically, there should be a balance of litter decomposition, net N mineralization, and subsequent litter N return. According to the N balance model, annual net N mineralization (150 kg N/ha) and N uptake (142 kg N/ha) are quite similar, but N returns from annual fine root mortality plus aboveground litterfall are somewhat lower (102 kg N/ha). N returns from woody debris are unknown but are likely to be small relative to fine root and litterfall returns, as this stand has not yet reached an old-growth stage where there is significant mortality of overstory stems (Jenkins and Parker 1998, Spetich and others 1999). Annual litterfall may have been underestimated by 10-20 percent because only autumnal litterfall was collected (Idol and others 1998). Even so, total litter returns are still 30-35 kg N/ha less than total N uptake. Assuming a woody production rate of approximately 5 Mg/ha with a N concentration of 0.2-0.4 percent (Perry 1994), perennial biomass N accumulation probably does not exceed 10-20 kg N/ha. Fruiting structures such as acorns (oaks), nuts (beech and hickories), and samaras (maples) may account for some of the remaining N.

1-8 Year-Old Stands

Figure 3 illustrates the N balance model for forest stands aged 1-8 years after harvest. Although woody debris (WD) from logging slash adds a significant quantity of organic matter to the litter pool (Idol and others 1999), the total N content is comparable to that found in the mature forest stand (156 kg N/ha). Because higher soil temperatures in the regenerating stands may lead to faster decomposition rates, the decay of this poor quality WD litter likely leads to an increase in soil microbial biomass N (SMBN) (283 kg N/ha). This increase in SMBN may depress annual net N mineralization rates in the first year or two after harvest (110 kg N/ha). By 6-8 years after harvest, however, SMBN is similar to pre-harvest levels (150 kg N/ha). At 6-8 years, net N mineralization and N uptake from the A (80 kg N/ha) but not the B (~50 kg N/ha) horizon is also similar to preharvest levels. Fine root mortality (55 kg N/ha) and the fine root litter pool (18 kg N/ha) are similar to preharvest levels.

Net N mineralization, N uptake, and litter production balance quite well in the model of recently harvested stands (figure 3). Although no data on fine root mortality or litterfall were collected for the stand aged 1-3 years, estimates at 4-5 years suggest these litter sources probably add 110-130 kg N/ha annually. Annual net N mineralization and N uptake also range from 110-130 kg N/ha. This suggests that little incremental biomass is being accumulated during the early stages of forest regrowth. This agrees with earlier studies that showed recently-harvested stands in this region are dominated by herbaceous annuals and perennials (Matson and Vitousek 1981, Idol and others 2000), plants that retain little residual biomass from year to year.

Table 1—Vegetation and Soil Characteristics for a Chronosequence of Upland Oak-Hickory Forests in Southern Indiana

Stand Age	Major Canopy Species	Major Understory Species	Dominant Soil Series	Soil Horiz.	Bulk Density ($g\ cm^{-3}$)	pH	Total C	Total N
						——($g\ cm^{-3}$)——		
0-8	*Liriodendron tuplipifera* *Quercus alba*	*Smilax* spp. *Rubus* spp	Gilpin	A	1.20	5.41	35.1	4.63
				B	1.32	4.88	6.10	1.26
10-15	*Prunus serotina* *Quercus Rubra*	*Asimina triloba* *Sassafras albidum*	Gilpin	A	1.05	5.50	31.2	4.43
				B	1.35	4.81	5.84	1.01
30-35	*Acer saccharum* *Prunus Serotina*	*Acer saccharum* *Asimina triloba*	Gilpin/ Wellston	A	0.95	4.59	31.3	4.68
				B	1.10	4.71	5.42	1.14
80-100	*Quercus alba*	*Acer saccharum*	Wellston	A	1.02	4.59	27.4	4.12
				B	1.20	4.49	6.75	1.41

Sampled depths are 0-8 cm for the A and 8-30 cm for the B horizons.

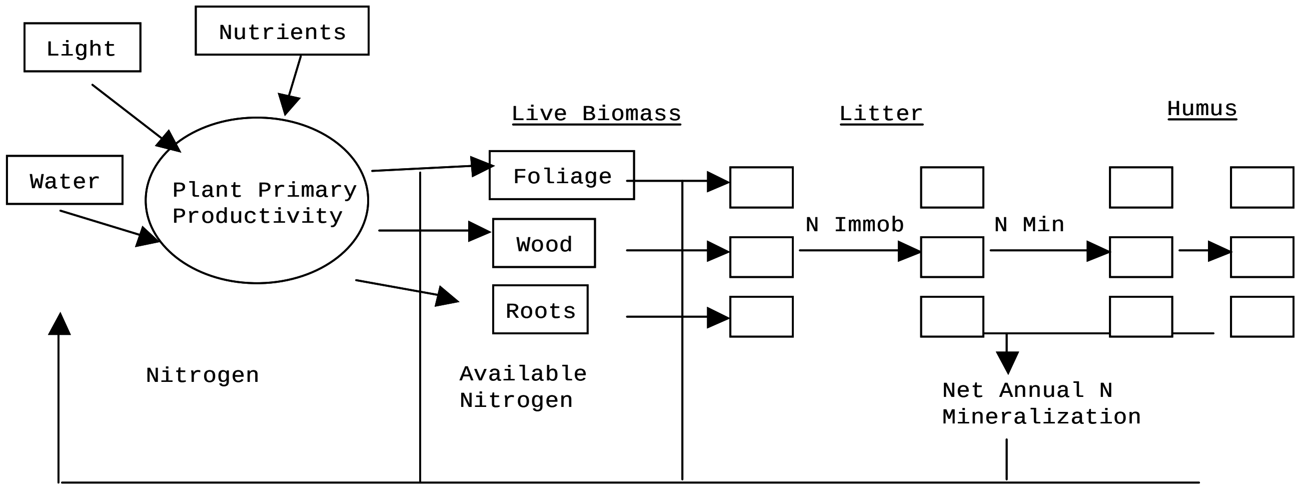


Figure 1—"VEGIE," a Generalized N Cycling Model (from Aber and others 1991). Values for boxes and arrows in kg N/ha-yr-1. Values in circles represent strength of correlations (Pearson's correlation coefficient, R).

10-15 Year-Old Stand

Figure 4 illustrates N cycling patterns at stand age 10-15 years. Annual litterfall N returns are lower than at 1-8 years (27 kg N/ha), but fine root turnover is higher (69 kg N/ha). Forest floor mass and the fine root litter pool are higher (69 and 26 N/ha, respectively), but the lack of large WD inputs plus a possible slowing of litter decomposition may contribute to lower SMBN in the A horizon (57 kg N/ha). The available N pool is somewhat lower in the A horizon (6.8 kg N/ha) but slightly higher in the B horizon (12 kg N/ha).

Net N mineralization in the A and B horizons (41 and 65 kg N/ha, respectively) is very similar to N uptake (44 and 67 kg N/ha, respectively). The total N uptake rate (111 kg N/ha) is slightly higher than the total litter production rate (96 kg N/ha), however, indicating some perennial biomass N accumulation. This is to be expected at this stage of forest development, as there is intense competition among tree saplings to reach the canopy before full canopy closure. Assuming a woody tissue N concentration of 0.2-0.4 percent, this balance of N uptake translates into a perennial biomass production rate of 12.5-25 Mg ha/yr.

30-35 Year-Old Stand

Figure 5 illustrates N cycling patterns at 30-35 years post-harvest. Annual litterfall N returns are higher at this stage

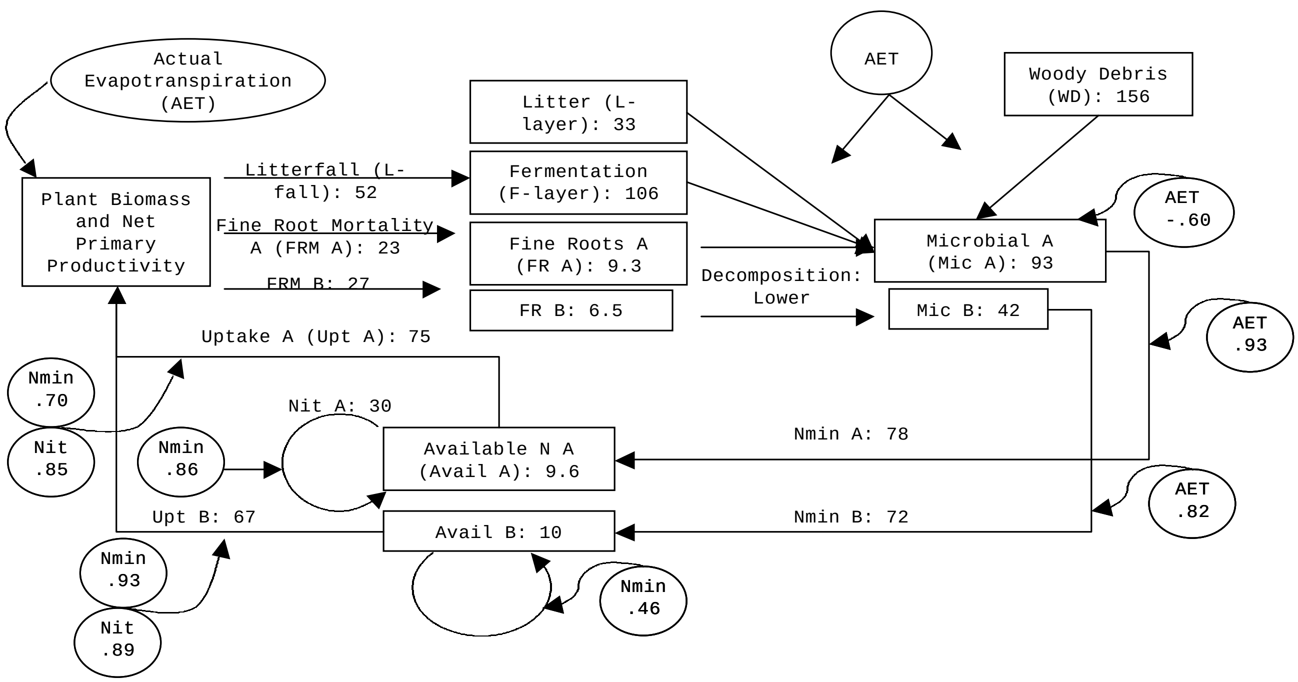


Figure 2—N Balance Model in an 80-100 Year Old Southern Indiana Upland Hardwood Forest. Values for boxes and arrows in kg N/ha/yr. Values in circles represent strength of correlations (Pearson's correlation coefficient, R).

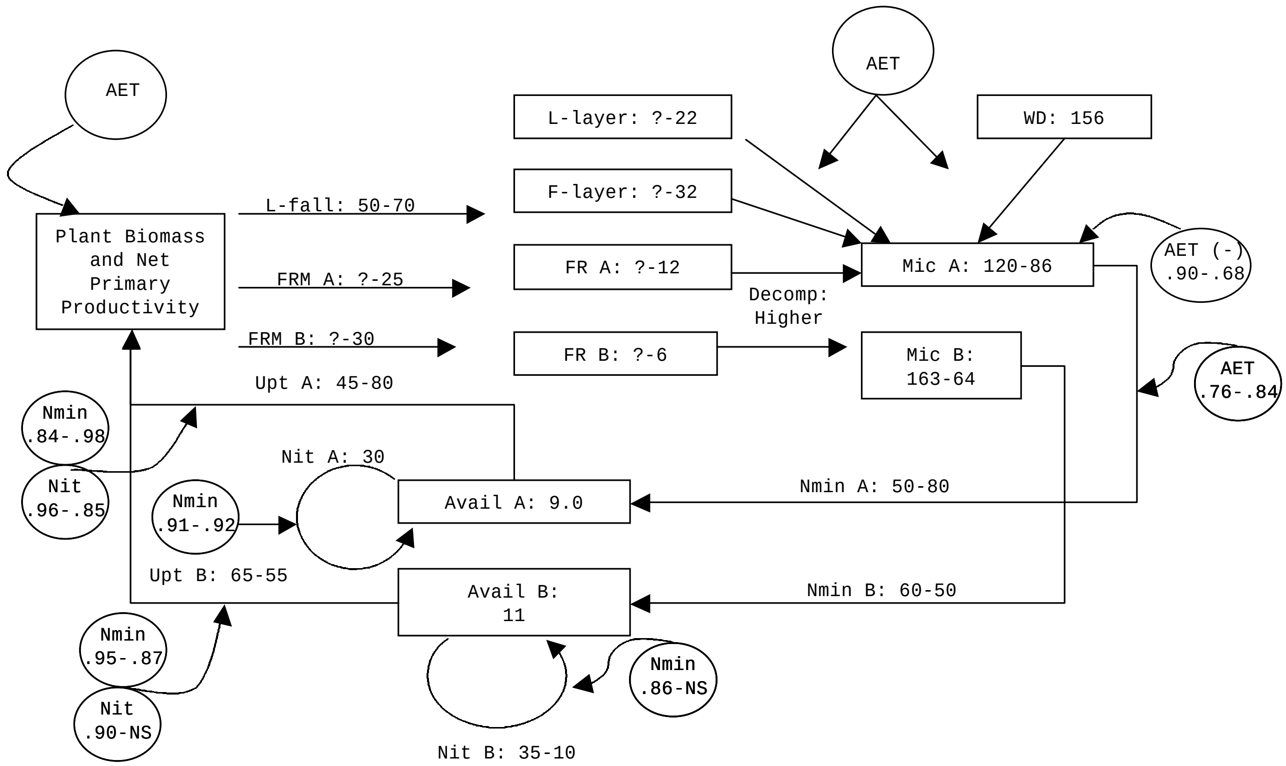


Figure 3—N Balance Model in Southern Indiana Upland Hardwood Forest Stands 1-8 Years Post-Harvest. Values for boxes and arrows in kg N/ha/yr. Values in circles represent strength of correlations (Pearson's correlation coefficient, R).

(38 kg N/ha) than at 10-15 years (27 kg N/ha), reflecting increased leaf area with increased stand age. Fine root mortality is similar in the A horizon (30 kg N/ha) but lower in the B horizon (32 kg N/ha). Forest floor mass is higher (98 kg N/ha), but the dead fine root pool is slightly lower (18 kg N/ha). Decomposition is assumed to be lower at this stage of forest development, but the SMBN pool is somewhat higher (141 kg N/ha) than at 10-15 years of age (112 kg N/ha), perhaps due to declining aboveground litter quality. The available N pool is somewhat higher in the A horizon (7.6 kg N/ha) but lower in the B horizon (9.0 kg N/ha).

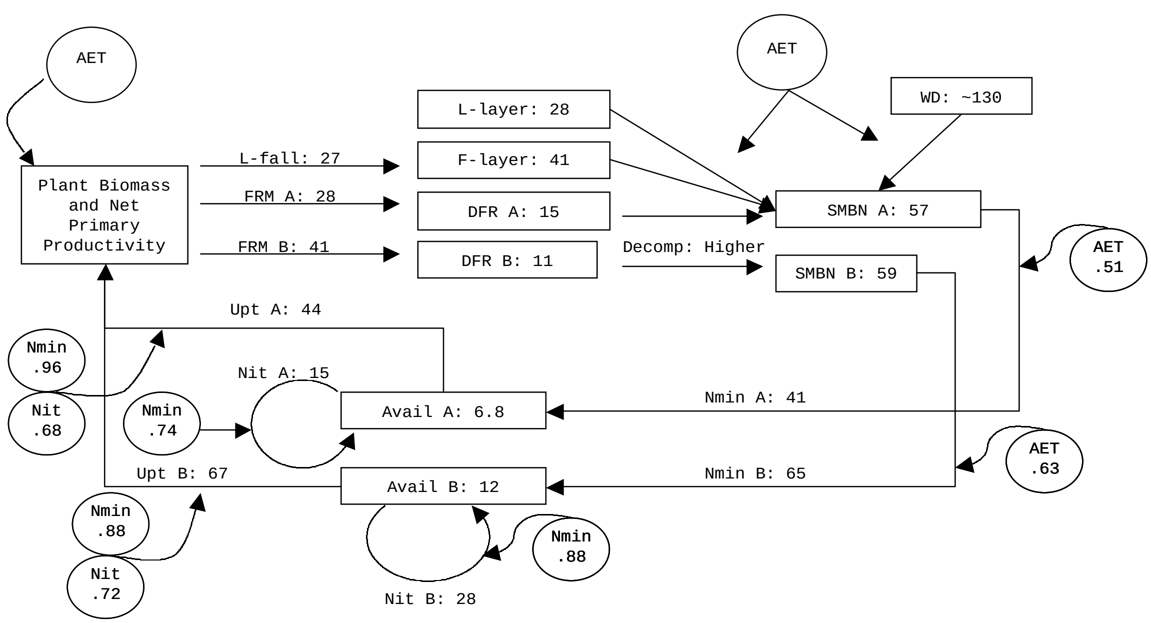


Figure 4—N Balance Model in a 10-14 Year-Old Southern Indiana Upland Hardwood Forest. Values for boxes and arrows in kg N/ha/yr. Values in circles represent strength of correlations (Pearson's correlation coefficient, R).

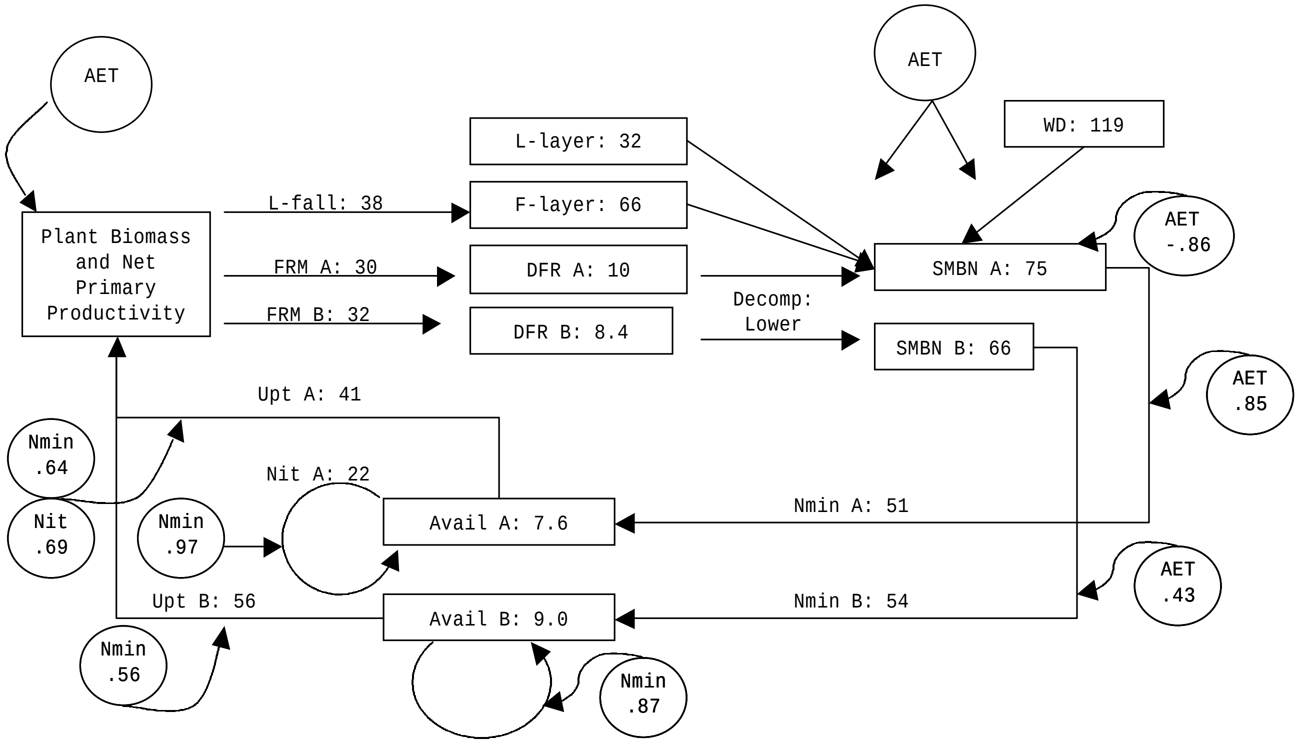


Figure 5—N Balance Model in a 29-33 Year-Old Southern Indiana Upland Hardwood Forest. Values for boxes and arrows in kg N/ha/yr. Values in circles represent strength of correlations (Pearson's correlation coefficient, R).

In the B horizon, net N mineralization (54 kg N/ha) is similar to N uptake (56 kg N/ha), but in the A horizon, net N mineralization (51 kg N/ha) is somewhat greater than N uptake (41 kg N/ha). Total N uptake (97 kg N/ha) and net N mineralization (105 kg N/ha), however, were similar to total litter production (100 kg N/ha), indicating that perennial plant growth may be slowing in this stand, and N cycling is approaching steady-state. This is in contrast to the higher net N mineralization and uptake (~145 kg N/ha) vs. total litter production (102 kg N/ha) rates in the mature forest stand (figure 2).

Controls Over N Cycling Rates

In stands of all ages, actual evapotranspiration (AET) correlates significantly and in some cases strongly with net N mineralization and N uptake. There is no consistent pattern with stand age, but in general relationships were stronger between AET and N cycling in the A horizon than in the B horizon. Relationships were generally strongest with net N mineralization and weakest with soil microbial biomass N and net nitrification.

The strongest relationships, however, were among the N cycling processes themselves. In general, net nitrification and N uptake were more strongly correlated with net N mineralization than with AET. In stands that are N-limited, N supply rates likely exert the strongest control over nitrification and N uptake, with environmental conditions (e.g., soil moisture and temperature) influencing the rate at which available N is nitrified or immobilized by plants or soil microorganisms.

CONCLUSIONS

The conceptual models presented in this study were derived from investigations of N cycling pools and processes at different stages of forest development. In general, there was a good balance of N mineralization, N uptake, and litter N returns in the regenerating forest stands; however, in the mature stand, there seemed to be more N taken up than returned via fine roots and autumnal litterfall. N mineralization and uptake were higher in the mature stand (140-150 kg ha/yr) than in the regenerating stands (80-100 kg ha/yr). Although actual evapotranspiration (AET) correlated significantly with N cycling processes at all stages of forest development, nitrification and N uptake correlated more strongly with N mineralization than with AET. Thus, although N cycling processes are well-balanced at different stages of forest development, harvesting may lead to declines in overall N cycling rates for at least the first 30-35 years.

REFERENCES

Aber, J.D.; Melillo, J.M.; Nadelhoffer, K.J.; Pastor, J.; Boone, R.D. 1991. Factors controlling nitrogen cycling and nitrogen saturation in northern temperate forest ecosystems. Ecological Applications. 1: 303-315.

Attiwill, P.M.; Adams, M.A. 1993. Tansley review No. 50. Nutrient cycling in forests. New Phytologist. 124: 561-582.

Crow, T.R.; Mroz, G.D.; Gale, M.R. 1991. Regrowth and nutrient accumulations following whole-tree harvesting of a maple-oak forest. Canadian Journal Forest Research. 21: 1305-1315.

Frazer, D.W.; McColl, J.G.; Powers, R.F. 1990. Soil nitrogen mineralization in a clearcutting chronosequence in a Northern California conifer forest. Soil Science Society America Journal. 54: 1145-1152.

Gholz, H.L.; Hawk, G.M.; Campbell, A.; Cromack, Jr. K.; Brown, A.T. 1985. Early vegetation recovery and element cycles on a clear-cut watershed in western Oregon. Canadian Journal Forest Research. 15: 400-409.

Hendrickson, Q.Q. 1988. Biomass and nutrients in regenerating woody vegetation following whole-tree and conventional harvest in a northern mixed forest. Canadian Journal Forest Research. 18: 1427-1436.

Idol, T.W.; Pope, P.E.; Figler, R.A.; Ponder, Jr., F. 1999. Characterization of coarse woody debris across a 100 year chronosequence of upland oak-hickory forests. In: Stringer, J.W.; Loftis, D.L., eds. Proceedings 12th central hardwood forest conference. Gen. Tech. Rep. SRS-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 60-67.

Idol, T.W.; Pope, P.E.; Ponder, Jr., F. 2000. Fine root dynamics across a chronosequence of upland oak-hickory forests. Forest Ecology Management. 127: 153-167.

Idol, T.W.; Pope, P.E.; Tucker, J.; Ponder, Jr. F. 1998. The role of fine root dynamics in the N and P cycles of regenerating upland oak-hickory forests. In: Waldrop, T.A., ed. Proceedings 9th Biennial Southern Silvicultural Research Conference. Gen. Rep. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 136-140.

Jenkins, M.A.; Parker, G.R. 1998. Composition and diversity of woody vegetation in silvicultural openings of southern Indiana forests. Forest Ecology Management. 10: 57-74.

Matson, P.A.; Vitousek, P.M. 1981. Nitrogen mineralization and nitrification potentials following clearcutting in the Hoosier National Forest, IN. Forest Science. 27: 781-79.

Nadelhoffer, K.J.; Aber, J.D.; Melillo, J.M. 1984. Seasonal patterns of ammonium and nitrate uptake in nine temperate forest ecosystems. Plant Soil. 80: 321-335.

Perry, D.A. 1994. Forest ecosystems. Baltimore: John Hopkins University Press. 649 p.

Pritchett, W.L.; Fisher, R.F., eds. 1987. Properties and management of forest soils. New York: Wiley.

Spetich, M.A.; Parker, G.R. 1999. Regional distribution and dynamics of coarse woody debris in midwestern old-growth forests. Forest Science. 45: 302-313.

THE RELATIONSHIP BETWEEN SOILS AND FOLIAR NUTRITION FOR PLANTED ROYAL PAULOWNIA

James E. Johnson, David O. Mitchem, and Richard E. Kreh[1]

Abstract—Royal paulownia is becoming an important hardwood plantation species in the southern U.S. A study was done to investigate two novel site preparation techniques for aiding the establishment of royal paulownia seedlings in the Virginia Piedmont. The effects of these treatments on the foliar nutrition of first year seedlings was determined, as was the relationship between soil fertility levels and foliar nutrition in the three study blocks. Seedlings established following both trenching and subsoiling treatments had significantly higher levels of foliar P than the control seedlings. Seedlings growing in the trenched plots had higher levels of foliar N than the control seedlings. For example, the seedlings growing in the trenched plots had average foliar N levels of slightly over 25,000 mg/kg, while the control seedlings had levels of 17,250 mg/kg. The seedlings in control plots also had lower, but not significantly so, foliar levels of K, Ca, Fe, and Mn. Soil fertility levels, based on soil test measurements, had positive and significant relationships with the foliar nutrient levels, as determined by simple linear regression.

INTRODUCTION

Royal paulownia (*Paulownia tomentosa* (Thurb.) Steud.) is becoming an important hardwood plantation species in the Southern U.S. Originally introduced to the U.S. from China in the early 1800's, royal paulownia has become naturalized throughout much of the eastern U.S. Today the markets for paulownia wood remain in Japan, where the wood is used for a variety of products, including lumber for furniture, handicrafts, musical instruments, shoes, etc. (Hardie and others 1989). Landowners are interested in techniques for establishing and growing paulownia tree crops for the export market (Johnson and others 1992, Kays and others 1998).

This study was established to investigate the usefulness of two novel site preparation techniques, trenching and subsoiling for early establishment and growth of royal paulownia. Paulownia growth is best in China on light textured soils, with clay contents less than 10 percent (Zhao-Hua and others 1997). The heavy textured soils found in the Piedmont have proven problematic for paulownia establishment, survival, and growth. One aspect of paulownia field performance, foliar nutrition, will be reported here.

METHODS

Study Area

The study was established at Virginia Tech's Reynolds Homestead Forest Resources Research Center located in the Piedmont physiographic province in Patrick County, Virginia (latitude 36°40′N, longitude 80°10′W). Three abandoned agricultural fields were selected for the study sites, with each field representing a complete block. All three fields were in grass and broad-leaved weed cover.

The study area experiences a warm, humid continental climate, with a mean annual temperature of 15°C, mean annual precipitation of 114 cm, and mean growing season precipitation of 79 cm. Temperatures typically range from -1°C in winter to 29°C in summer. The normal growing season length is 190 days, with April 20 as the most likely date of the last killing frost in the spring, and November 1 as the most likely date of the first killing frost in the fall.

Soils in the study area are in the Cecil series, and are clayey, kaolinitic, thermic Typic Hapludults. These soils are deep and well-drained, and formed in weathered granite gneiss, quartz schist, and quartzite. The A horizons are thin to absent due to surface erosion when the fields were in agricultural production.

Seedling Propagation

Seed pods were collected from selected wild trees growing in southwestern Virginia and air-dried, and then seeds were extracted and stored in sealed containers at 4°C. In the late summer of 1993, seeds were broadcast sown in greenhouse flats containing a 1:1 by volume mixture of Pro-Mix BX® and sand. Following germination, the germinants were manually transplanted into cone-tainers, with two to four germinants per pot. The seedlings were grown in a heated (temperature above 15°C) greenhouse under

[1]Professor of Forestry and Associate Dean - Outreach, College of Natural Resources, Department of Forestry (0324), Virginia Tech, Blacksburg, VA 24061; Forestry Research Specialist; Senior Research Associate and Superintendent, Reynolds Homestead Forest Resources Research Center, PO Box 70, Critz, VA 24082, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Soil chemical properties for each site preparation treatment in each block at the Reynolds Homestead Forest Resources Research Center

Block	Site Preparation Treatment	pH	Anaerobically Mineralized N (mg/kg)	Total N (mg/kg)	Total C (%)	Extractable (mg/kg) P	K	Ca	Mg	Fe	Mn
1	Subsoil	5.7	24.0	636	0.98	0.12	40.6	420.5	157.4	1.83	16.9
	Trench	5.4	23.7	705	1.06	0.12	32.8	415.9	77.2	1.00	50.2
	Control	5.5	32.8	776	1.16	0.12	61.9	430.2	145.0	1.49	35.6
	Mean	5.5	26.8	706	1.07	0.12	45.1	422.2	126.5	1.44	34.2
2	Subsoil	5.7	26.4	701	1.16	0.12	31.2	394.0	122.9	2.20	7.3
	Trench	5.5	20.6	619	0.95	0.12	25.0	374.9	130.9	5.89	4.8
	Control	5.4	18.6	617	0.96	0.12	20.3	421.5	143.1	4.24	4.7
	Mean	5.5	21.8	646	1.02	0.12	25.5	396.8	132.3	4.11	5.6
3	Subsoil	5.4	31.5	598	1.05	0.97	81.9	314.7	112.0	2.90	6.7
	Trench	5.7	39.1	651	1.01	2.31	99.8	410.5	143.8	2.58	7.9
	Control	5.6	51.1	708	1.05	4.18	89.8	359.3	116.0	3.48	8.9
	Mean	5.5	40.5	652	1.03	2.49	90.5	361.5	123.9	2.99	7.8

natural light conditions, with water and nutrients added regularly, for 14 weeks. After 3 weeks, the most vigorous seedling in each pot was selected and the others were removed. Following the 14-week greenhouse period, the pots were moved outside to a slathouse and allowed to harden off until planting.

Site Preparation and Plantation Establishment

During the early spring of 1994, three site preparation treatments were installed on 0.05-ha plots in the three blocks. Treatment one consisted of drawing a single subsoil shank behind a tractor on a 2-m x 2-m grid throughout the block. The subsoil shank penetrated to a depth of approximately 75 cm, creating a grid pattern. Treatment two consisted of creating a 2-m x 2-m grid of 10 cm-wide x 60 cm-deep trenches throughout the block. The trenches were filled with soil and two loblolly pine (*Pinus taeda*) poles placed at depths of 40 and 25 cm. The pine poles were cut from a thinning operation in a nearby plantation. The purpose of both the subsoil and trenching treatments was to break up the dense subsoil and create

Table 2—Soil physical properties for each site preparation treatment in each block at the Reynolds Homestead Forest Resources Research Center

Block	Site Preparation Treatment	Bulk Density (g/cm^3)	Soil Strength (kg/cm^2)	Soil Moisture (%)	Coarse Fragments (%)	Sand (%)	Silt (%)	Clay (%)	Textural Class
1	Subsoil	1.2	4.99	35.0	0.7	35	28	37	clay loam
	Trench	1.4	8.44	25.8	0.8	40	23	38	clay loam
	Control	1.2	5.48	32.0	0.6	38	28	34	clay loam
	Mean	1.3	6.33	30.9	0.7	38	26	36	clay loam
2	Subsoil	1.4	9.42	20.6	12.4	44	22	34	clay loam
	Trench	1.3	7.87	21.2	5.9	47	20	34	sandy clay loam
	Control	1.5	7.38	21.2	12.1	46	19	37	sandy clay loam
	Mean	1.4	8.23	21.0	10.1	46	20	35	clay loam
3	Subsoil	1.6	8.86	21.0	17.6	38	32	31	clay loam
	Trench	1.5	7.95	21.6	15.1	42	28	31	clay loam
	Control	1.6	9.35	22.2	25.5	46	26	29	clay loam
	Mean	1.6	8.72	21.6	19.4	42	29	30	clay loam

Table 3—Foliar nutrient levels for each site preparation treatment in each block at the Reynolds Homestead Forest Resources Research Center

Block	Site Preparation Treatment	Foliar Nutrient Level (mg/kg) N	P	K	Ca	Mg	Fe	Mn
	Subsoil	14,800	1,420	7,790	10,940	3,090	218	24
1	Trench	24,500	1,700	9,820	8,550	2,870	82	53
	Control	17,000	1,400	9,020	7,910	2,890	103	22
	Mean	18,800	1,510	8,880	9,130	2,950	134	33
	Subsoil	21,900	1,360	8,670	7,600	3,380	59	21
2	Trench	22,700	1,450	7,710	7,540	3,680	80	20
	Control	12,900	1,010	5,140	6,350	2,630	229	16
	Mean	19,200	1,270	7,170	7,160	3,230	123	19
	Subsoil	29,600	3,540	14,240	5,070	3,680	65	20
3	Trench	28,000	3,290	12,890	6,480	3,950	64	20
	Control	21,900	2,590	10,980	7,140	4,050	72	19
	Mean	26,500	3,140	12,700	6,230	3,890	67	20

root channels for the planted seedlings. The final site preparation treatment consisted of a control.

During May of 1994, 100 containerized royal paulownia seedlings were hand-planted on a 2-m x 2-m grid in each of the site-prepared plots, at the intersections of the subsoil channels or the trenches. In the control plots, the planting spots were hand-scalped, but this was not necessary in the site-prepared plots since there was adequate surface disturbance to remove the sod cover. As a secondary treatment, each plot was split into two subplots, and 50 seedlings in each subplot were surrounded with a 91-cm x 91-cm Vispore® weed mat. An additional 50 seedlings were left untreated.

Soil Sampling and Field Measurements

Prior to the installation of site preparation treatments, soil characterization samples were collected from each of the 18 subplots in the study. Five 30 cm-deep push tube samples were collected from random locations in each subplot, then composited in the field.

Simultaneously with the collection of samples for soil characterization, soil moisture samples were collected at the same five locations, to a depth of 15 cm. These samples were likewise composited and returned to the lab for gravimetric analysis. Comparative soil strength measurements were also obtained at the same locations, using a SOILTEST penetrometer to a depth of 5 cm. Additionally, three randomly located bulk density samples, to a depth of 5 cm, were collected in each subplot using an AMS soil core sampler.

Following installation of the site preparation treatments, gravimetric soil moisture samples were collected again from five random locations within each subplot. Soil penetrometer measurements were also repeated. In the control plots, five readings were made in random locations

Table 4—Site preparation treatment effects on royal paulownia foliar nutrient levels

Site Preparation Treatment	Foliar Nutrients (mg/kg) N	P	K	Ca	Mg	Fe	Mn
Subsoil	22,100 ab[1]	2,110 a	10,240 a	7,870 a	3,380 a	114 a	21 a
Trench	25,100 a	2,150 a	10,140 a	7,520 a	3,500 a	75 a	31 a
Control	17,300 b	1,670 b	8,380 a	7,140 a	3,190 a	135 a	19 a

[1]Means followed by the same letter are not significantly different at the 0.10 level.

within each subplot. In the site-prepared plots, five readings per subplot were randomly taken in the subsoil channels and trenches, as well as in the undisturbed portions of the subplots. Likewise, the bulk density sampling was repeated in a fashion similar to the penetrometer measurements, except three bulk density samples were collected from each of the disturbed and undisturbed areas of the site-prepared subplots.

Foliar Sampling

During September 1994, sun leaves from four randomly selected seedlings in each site preparation treatment within each block were harvested and allowed to air-dry in paper bags.

Laboratory Methods

The characterization soil samples were air-dried and ground to pass a 2-mm sieve. Available P, K, Ca, Mg, Fe, and Mn were extracted using the dilute double-acid procedure with 0.05N HCl and 0.025N H_2SO_4 (Kuo 1996), with the extract analyzed using a Jarrell-Ash ICAP-9000 inductively coupled plasma emission spectrometer. An estimate of nitrogen availability was determined using the anaerobic incubation technique (Keeney 1982). Total nitrogen was determined using the micro-Kjeldahl method (Bremner and Mulvaney 1982). Soil pH was determined using a glass electrode in a 2:1 soil:water mixture. Percent organic carbon was determined using a LECO CR-12 carbon analyzer, and particle size analysis was conducted using the hydrometer method. Bulk density was determined gravimetrically, with correction for coarse fragments greater than 2 mm.

Foliage was oven-dried to a constant weight at 65°C, then ground in a Wiley mill to pass a 1-mm sieve. The ground tissue was dry-ashed in a muffle furnace at 500°C, dissolved in 6N HCl and analyzed for P, K, Ca, Mg, Fe, and Mn using a Jarrell-Ash ICAP-9000 inductively coupled plasma emission spectrometer. Total nitrogen was determined using the micro-Kjeldahl method (Bremner and Mulvaney 1982).

Statistical Analysis

This study was established as a randomized complete block, split-plot design, with site preparation treatments as major plots and a weed control mat treatment comprising the minor plots. There were three major plot site preparation treatments (subsoil, trench, and control) randomly applied in each of the three blocks, and two weed control treatments (mat or no-mat) applied to two subplots within each major plot. Thus, there were three blocks, three plots per block, and two subplots per plot. Each subplot had 50 seedlings. All measurements were averaged at the subplot level to create the experimental unit.

Foliar nutrient levels were subjected to an analysis of variance, followed by Duncan's Multiple Range Test at the 0.10 level. The analysis of variance revealed no effect of the weed control mats, so this factor was dropped from further analysis. Soil and foliar nutrient levels were compared using simple linear regression analysis.

RESULTS AND DISCUSSION

Soil Properties

Soil chemical and physical properties are displayed in tables 1 and 2. All three blocks had similar pH levels, with 5.5 being the average for each block. Block 1 tended to have slightly higher levels of total soil N, although Block 3 had the highest level of anaerobically mineralized N, at 40.5 mg/kg. Total C levels ranged from 1.02 to 1.07 percent. Levels of soil P were quite low on Blocks 1 and 2, averaging only 0.12 mg/kg. Soil P in Block 3 averaged 2.49 mg/kg. Block 3 tended to be richer also in soil K. Bulk densities tended to be consistent across the blocks, ranging from 1.3 g/cm^3 in Block 1 to 1.6 g/cm^3 in Block 3 (table 2). On the date that soil moisture was sampled, Block 1 had comparatively higher levels, at 30.9 percent compared to 21.0 and 21.6 percent for Blocks 2 and 3, respectively. Block 1 also had much lower levels of coarse fragments, with only 0.7 percent by weight. Blocks 2 and 3 averaged 10.1 and 19.4 percent, respectively. Across the study area the predominant soil textural class was clay loam (table 2).

Foliar Nutrient Levels

Foliar nutrient levels for the sampled seedlings are presented in table 3. Some block to block differences were noted, as well as differences between the treatments (table 4). Foliar N levels ranged from 18,800 to 26,500 mg/kg (table 3). P levels ranged from 1,270 to 3,140 mg/kg. N, P, and K foliar levels were considerably higher in Block 3, which relates well to the soil fertility levels shown in table 1.

Treatment effects on foliar nutrient levels were noted with only two nutrients, N and P (table 4). For N the seedlings growing on the trenched plots had significantly higher levels than the control seedlings. The seedlings growing on the subsoiled plots had intermediate levels, but they were not significantly greater than the control seedlings. Foliar N levels ranged from a low of 17,300 mg/kg for the control seedlings to 25,100 mg/kg for the seedlings growing on the trenched plots. For foliar P, both site preparation treatments led to seedlings with significantly higher levels than the control seedlings (table 4). The range in foliar P was from 1,670 mg/kg for the control seedlings to 2,150 mg/kg for the seedlings growing in the trenched plots. No significant differences were noted for any of the other treatments.

Relationship Between Soil Fertility and Foliar Nutrient Levels

The relationship between soil fertility and royal paulownia foliar nutrition is shown graphically in figure 1. Soil nutrient levels were regressed against the foliar nutrient levels for N, P, K, and Ca. Data were pooled at the block level, since soil sampling did not match the root zone of the individual seedlings from which leaf samples were collected. Therefore, the data set is limited to the averages of the soil samples and leaf samples for the three blocks. Nevertheless, strong and positive correlations were determined for all of the nutrients studied. Coefficients of determination ranged from a low of 0.911 for N to a high of 1.00 for K (figure 1). The inference is that royal paulownia is quite

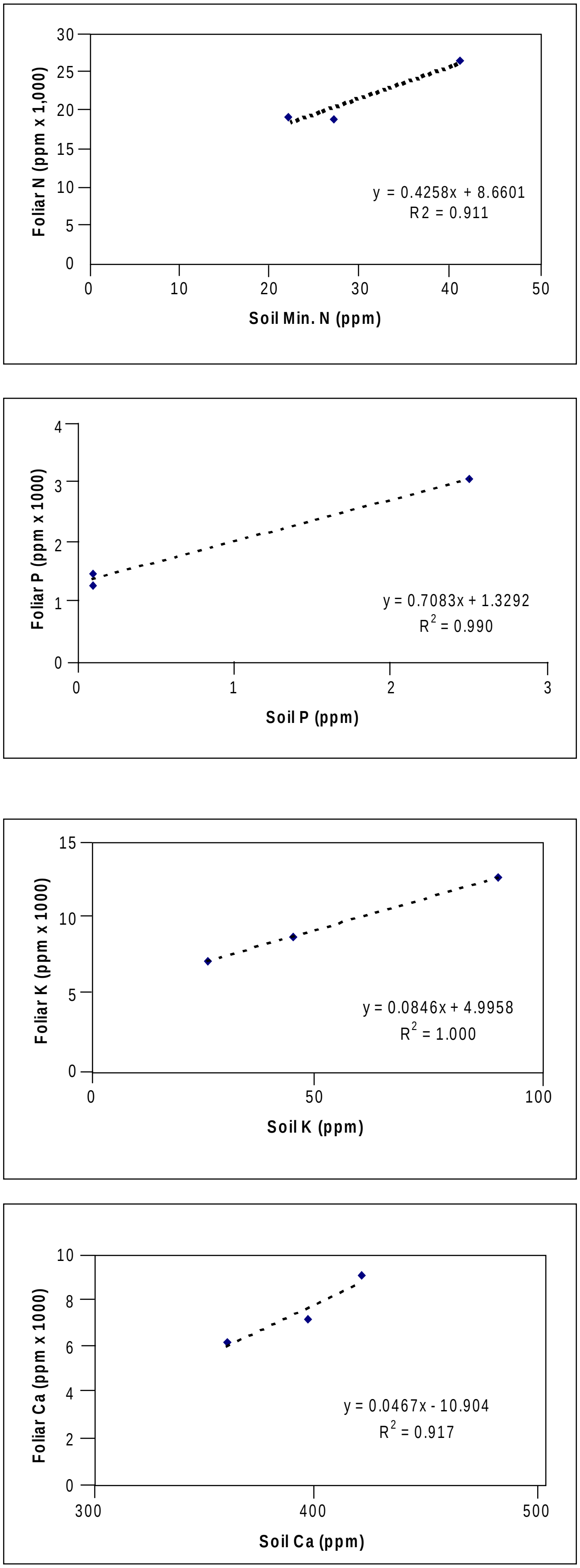


Figure 1—Relationships between soil fertility and royal paulownia foliar nutrition levels.

sensitive to soil fertility, a point that has been noted by others (Beckjord and McIntosh 1983, Graves and Stringer 1989). Although information on fertilizer regimes for royal paulownia are not well developed, it is apparent that foliar nutrition is closely related to soil nutrient levels, and fertilizer additions may be used to correct deficiencies. None of the seedlings in this study exhibited characteristic foliar nutrient deficiencies. Although leaf weights were not determined, royal paulownia seedlings and saplings are noted for having very large leaves. This indicates that on a total weight basis, paulownia may be quite demanding of nutrients. Foliar nutrition is also closely related to plant growth, so it is important to correctly balance foliar nutrient concentration (reported here) and nutrient content (Haase and Rose 1995, Cornelissen and others 1997).

CONCLUSIONS

Foliar nutrient levels for first year royal paulownia seedlings growing in plots of three different site preparation treatments were reported here. The treatments increased foliar concentrations of N and P, but did not affect foliar K, Ca, Mg, Fe, or Mn. Strong, positive correlations were found between soil fertility (expressed as extractable soil nutrients, or, in the case of nitrogen, anaerobically mineralizable) and foliar nutrient levels for N, P, K, and Ca. Royal paulownia appears to be quite sensitive to soil fertility, indicating that fertilization may be a viable treatment in areas of low fertility.

REFERENCES

Beckjord, P. J.; M. S. McIntosh. 1983. Paulownia tomentosa: effects of fertilization and coppicing in plantation establishment. Southern Journal of Applied Forestry. 7(2): 81-84.

Bremner, J. M.; Mulvaney, C. S. 1982. Nitrogen - total. In: Page, A. L.; Miller, R. H.; Keeney, D. R.,eds. Methods of Soil Analysis, Part 2. 2nd ed. Agronomy Series No. 9, Amer. Soc. of Agronomy, Madison, WI: 595-622.

Cornelissen, J. H. C.; M. J. A. Werger; P. Castro-Diez; J.W.A. van Rheenen; A. P. Rowland. 1997. Foliar nutrients in relation to growth, allocation and leaf traits in seedlings of a wide range of woody plant species and types. Oecologia 111: 460-469.

Graves, D. H.; Stringer, J. W. 1989. Paulownia — a guide to establishment and cultivation. Univ. of Kentucky Coop. Extension Serv. FOR-39. Lexington, KY. 8 p.

Haase, D. L.; R. Rose. 1995. Vector analysis and its use for interpreting plant nutrient shifts in response to silvicultural treatments. Forest Science. 41(1) 54-66.

Hardie, I.; Kundt, J.; Miyasaka, E. 1989. Economic feasibility of U.S. paulownia plantations. Journal of Forestry. 87(10): 19-24.

Johnson, J. E.; Pease, J. W.; Johnson, L. A.; Hopper, G. M. 1992. Tree crops for marginal farmland — royal paulownia, with a financial analysis. Virginia Cooperative Extension Pub. 446-606. Virginia Polytechnic Institute and State University, Blacksburg, VA. 22 p.

Kays, J.; Johnson, D.; Stringer, J. W. 1998. How to produce and market paulownia. Univ. of Maryland Cooperative Extension Service Bull. 319. College Park, MD. 22 p.

Keeney, D. R. 1982. Nitrogen—availability indices. In: Page, A. L.; Miller R. H.; Keeney, D. R., eds. Methods of Soil Analysis, Part 2. 2nd ed. Agronomy Series No. 9. America Society of Agronomy, Madison, WI: 722-730.

Kuo, S. 1996. Phosphorus. In: Sparks, D. L.;, ed. Methods of Soil Analysis, Part 3. Soil Science Society of America No. 5. Madison, WI: 869-919.

Zhao-Hua, Z.; Ching-Ju, C.; Xin-Yu, L.; Yao Gao, X. 1997. *Paulownia* in China: Cultivation and utilization. Asian Network for Biology Science and International Development Research Center, Ottawa, Canada. <http://www.idrc.ca/library/document/071235>.

GENOTYPE X FERTILITY INTERACTIONS IN SEEDLING SWEETGUM

Scott X. Chang and Daniel J. Robison[1]

Abstract—Genotype x fertility interactions may affect the suitability of sweetgum (*Liquidambar styraciflua* L.) for specific sites or the efficiency of nutrient use. To gain a better understanding of these interactions, 2-year-old sweetgum seedlings from two half-sib families were tested for growth response to N (0 and 100 kg/ha equivalent) and P (0 and 50 kg/ha equivalent) for one season in an outdoor pot study. Sweetgum seedlings responded rapidly to N and P treatments, in both stem and crown size. Nitrogen, P and family genotype explained 37, 21 and 10 percent of the response in basal diameter growth, respectively. The data suggest that screening sweetgum families for nutrient use efficiency may be worthwhile, and that balanced N and P applications are important for promoting seedling growth.

INTRODUCTION

Sweetgum (*Liquidambar styraciflua* L.) is an important hardwood timber species in the U.S. south (Kormanik 1990), and many hardwood plantations established for short-rotation pulpwood production in this region are sweetgum (Robison and others 1998). Developing genetically improved hardwoods for fast growth and high quality, and formulating site-specific and fertilization guidelines for hardwood plantation establishment have been rated as priorities for hardwood research in North America (Meyer 1996). A better understanding of the genetic variation in sweetgum growth response to silvicultural practices, such as fertilization, can improve the efficiency of timber production by best utilizing genetically improved planting stock.

Sweetgum families have been shown to respond differentially to N, but not to P applications (Nelson and Switzer 1990). Nelson and Switzer (1990) found significant family x fertility interactions for nitrogen. In three of the 4 families they tested, maximum growth response was at 200 kg N/ha, while the other half-sib family had its maximum growth response at 400 kg N/ha. Other studies in Mississippi by the same research group have reported various sweetgum genetic effects related to nutrition (Nelson and others 1995a, Nelson and Switzer 1992, Nelson and Switzer 1990, Nelson and others 1995b).

The current study examines genotype x fertility interactions in seedling sweetgum, using two half-sib families selected from among the circa 350 families in the NC State University - Hardwood Research Cooperative (NC State-HRC) genetic improvement program. These two families had in earlier work demonstrated substantially different responses to high and low fertility levels (Birks and Robison 2000). The aim of this work was to develop an understanding of the proportion of growth response attributable to genotype x fertility interactions. If such interactions are significant, then protocols for use in genetic selection, and site and fertilization decision-making, can be devised to best utilize specific genotypes. In the current study we specifically examine N and P fertility effects.

MATERIALS AND METHODS

This experiment was conducted in pots (22 cm diameter by 25 cm deep) out-of-doors at the Horticulture Field Laboratory of North Carolina State University in Raleigh, NC. Seed from two half-sib sweetgum families in the NC State-HRC program (F10022 and F10023), collected from a seed production area in St. George, SC (SC Forestry Commission land) were used in this work. Stratified seed were sown, two per pot from the same family, on 22 July 1999, into pots containing peat:vermiculite:field soil in a 6:3:1 (volume) ratio. The field soil (Congoree silt loam) was collected from an area with naturally occurring sweetgum in Raleigh, NC. After germination, all pots received a one-time application of 1.45 g of Osmocote™ slow-release fertilizer (14-14-14) to ensure adequate nutrition for healthy seedling development in the first growing season. Seedlings were thinned to one per pot in September 1999, to leave similarly sized plants among pots. Seedlings were overwintered outdoors and experimental treatments applied in the second growing season. Pots were widely spaced throughout the experiment to eliminate shading.

On 6 July 2000, four treatments were applied to both families, 1) no N or P (control), 2) no N and 50 kg/ha equivalent P, 3) 100 kg/ha equivalent N and no P, and 4) 100 kg/ha equivalent N and 50 kg/ha equivalent P. There were three pots for each family within each treatment. Fertilizers were applied as granular NH_4NO_3 and triple superphosphate. Pots received daily overhead irrigation.

Initial seedling size (ground-line basal diameter, total height, unit leaf weight, unit leaf area, and specific leaf area

[1]Graduate Student, Professor, Hardwood Research Cooperative, Department of Forestry, North Carolina State University, Raleigh, NC 27695, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

[SLA]) was measured on 23 June 2000. Leaf weight and area (then used to calculate SLA) were estimated by sampling five mid-crown fully expanded leaves from every tree. Final seedling size (same parameters as above, plus crown dimensions [height and width]) was measured on 7 September. Leaf samples were dried at 65 °C and weighed. Crown volume was calculated as a conoid from height and width measurements.

Statistical analyses were performed with SAS (SAS Institute, Cary, NC, Version 7.01).

RESULTS AND DISCUSSION

All initial seedling size measurements were compared by ANOVA among treatments. None differed significantly at $P < 0.05$ among treatment or family effects, or with any interactions. A few of the initial size measurements differed among treatments and families at $P < 0.10$. These were leaf weight among N, P and family factors, SLA by P levels, and height by family.

At the time of final measurements (two months after the treatments were applied) SLA was significantly ($P < 0.01$) affected by N, P, and an N x P interaction, but not by family (figure 1a). Without N addition seedling sweetgum SLA did not respond to P.

This response of SLA to N was consistent with those reported by Nelson and others (1995b). They reported SLA effects only three years after N application. In the current study we measured SLA changes in two months, and found a significant P effect. These changes in SLA suggest that when N and P are applied in correct proportion, seedlings will have greater photosynthetically active areas, and may grow more rapidly (Walters and Reich 1996). This may be of immediate relevance in sweetgum nurseries, and of longer-term importance in crown closure (and its effect on weeds) and productivity in field plantings. In herbaceous species it has been reported that nutrient additions do not impact SLA when photosynthetically active radiation is not limiting (Meziane and Shipley 1999), however our data indicates that sweetgum SLA was responsive to added nutrients under full light.

Initial and final basal diameters were significantly correlated, however initial and final heights were not. Basal diameter was affected by the experimental factors; family ($P < 0.01$), N ($P < 0.1$), and P ($P < 0.05$) (figure 1b). Family F10023 consistently had greater basal diameter than F10022, nitrogen addition was marginally significant at each P level, and P addition was significant regardless of the rate of N application. There were no interactions among these three factors with respect to diameter.

Seedling height was significantly affected by family ($P < 0.05$) and N application ($P < 0.05$) (figure 1c). However, in contrast to the findings for basal diameter growth, family F10022 was consistently taller than family F10023. No interactions with respect to height were found. In the current study the two month (current) growth increment was significant, corroborating earlier findings of rapid sweetgum response to resource availability (Hopper and others 1992, Lockaby and others 1997, Nelson and Switzer 1990, 1992, Nelson and others 1995a).

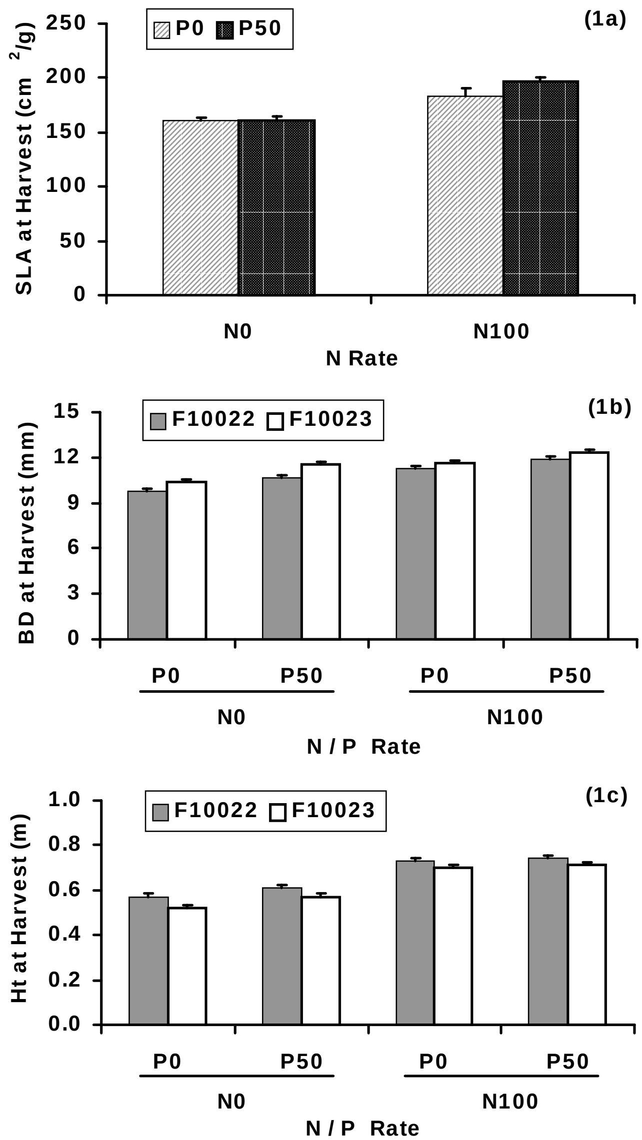


Figure 1—Mean + SE ($n = 4$) response of 2-year-old sweetgum to N and P application, and family (F10022 and F10023), by specific leaf area (SLA), seedling basal diameter (BD) and height (Ht), two months after treatment. figure 1a shows the interaction between N and P ($P < 0.05$) treatments on SLA when family was not significant. In figure 1b, N ($P < 0.10$), P ($P < .0.05$) and family ($P < 0.05$) were significant; and in figure 1c, N and family ($P < 0.05$) were significant.

Physiological responses to nutrient additions often appear first in foliar characteristics and crown expansion. Crown width in the current study was significantly correlated with initial seedling height ($P < 0.05$), and was affected by N ($P < 0.01$) and P ($P < 0.01$) additions (figure 2a). Differences in crown width between the families were not significant, nor were there any significant treatment

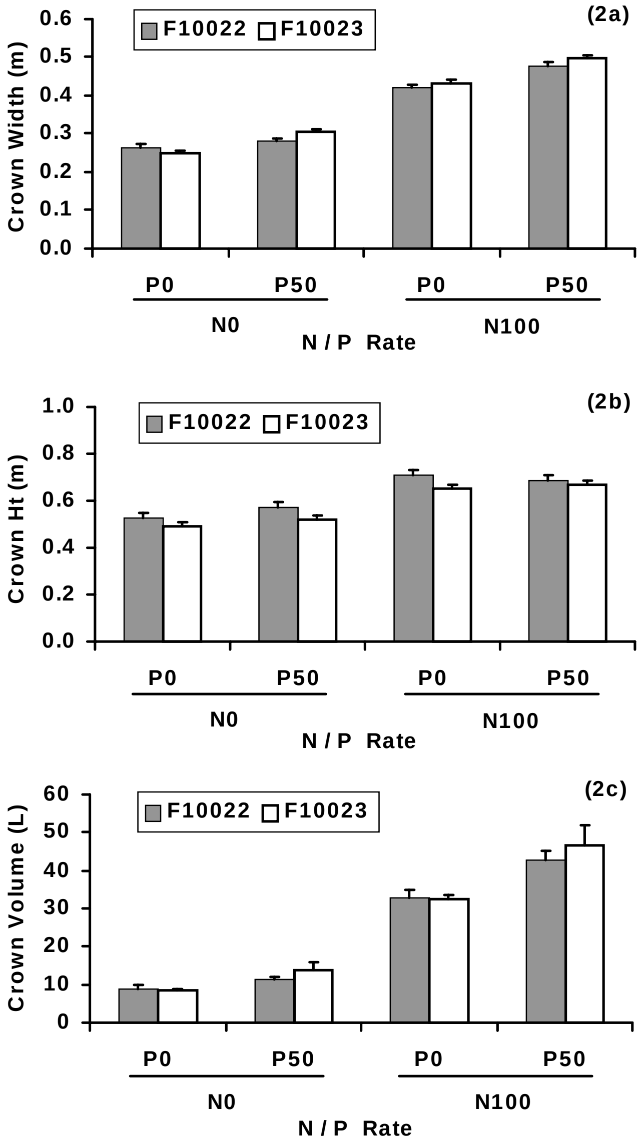


Figure 2—Mean + SE (n = 4) response of 2-year-old sweetgum to N and P application, and family (F10022 and F10023), by crown width, crown height and crown volume, two months after treatment. In figure 2a, N and P were significant (P < 0.05); in figure 2b, N and family were significant (P < 0.05); and in figure 2c, N and P were significant (P < 0.05).

interactions. Crown height was significantly correlated with initial SLA (P < 0.05), and was affected by family (P < 0.05) and N (P < 0.01) application (figure 2b). For crown height (similar to total height, figure 1c), family 10022 was greater than family 10023. When crown width and height were integrated into crown volume, family differences were not significant (figure 2c), although N and P additions increased crown volume. No interaction between N and P was found.

The significant effects of the N and P treatments on crown volume (Fig 2c) and SLA (Fig 1a) may be responsible, through their relationship with photosynthetic area, for the seedling growth responses found. With respect to basal diameter, N, P and family explained 37, 21 and 10 percent of the growth response, respectively.

CONCLUSIONS

N and P application affected the growth rate of two-year-old sweetgum seedlings, two months after treatment. Two half-sib families responded to the N and P treatments differently, indicating significant genotype x fertility variation in sweetgum. Thus it may be possible to select genotypes that are more efficient in nutrient use. Results suggest the need to balance N and P applications to seedling sweetgum, and that N generally limits the response to P.

ACKNOWLEDGMENTS

The authors thank Peter Birks, David Gadd, Jim Bridges, Jamie Schuler and other staff of the NC State-HRC for assistance with this project. This work was supported by the industrial and state agency members of the NC State-HRC.

REFERENCES

Birks, P.J; Robison, D.J. 2000. Sweetgum family seedling screening and response to stress. In: Proceedings 25th Biennial Southern Forest Tree Improvement Conf; 1999 11-14; New Orleans, LA. Southern Forest Tree Improvement Comm., sponsored pub. No. 47: 36-39.

Hopper, G.M.; Buckner, E.R.; Mullins, J.A. 1992. Effects of weed control and fertilization on plantation establishment and growth of green ash, sweetgum, and loblolly pine: four-year results. In: Brissette, J.C., ed. Proceedings of the Seventh biennial southern silvicultural research conference; 1992 November 17-19, Mobile, AL. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 357-360.

Kormanik, P.P. 1990. Sweetgum. In: Burns, R.M. and Honkala, B.H. (Tech. Coords.). Silvics of North America: 2. Hardwoods. USDA For. Serv., Wash., D.C. Agric.Handb. 654. Washington, D.C: U.S. Department of Agriculture. 400-405.

Lockaby, B.G.; Clawson, R.G.; Baker, T. 1997. Response of three hardwood species to irrigation and fertilization on an upland site. Southern Journal of Applied Forestry. 21: 123-129.

Meyer, D.A. 1996. Research priorities for North American hardwoods. In: Proceedings of the Twenty-Fourth Annual Hardwood Symposium, Putting Research to Work for the Hardwood Industry: New Technology Available Today; 1996 May 8-11; Cashiers, NC; 15-25.

Meziane, D.; Shipley, B. 1999. Interacting determinants of specific leaf area in 22 herbaceous species: effects of irradiance and nutrient availability. Plant Cell Environ. 22: 447-459.

Nelson, L.E.; Shelton, M.G.; Switzer, G.L. 1995a. Aboveground net primary productivity and nutrient content of fertilized plantation sweetgum. Soil Science Society of America Journal. 59: 925-932.

Nelson, L.E.; Shelton, M.G.; Switzer, G.L. 1995b. The influence of nitrogen applications on the resorption of foliar nutrients in sweetgum. Canadian Journal of Forestry Research. 25: 298-306.

Nelson, L.E.; Switzer, G.L. 1990. Sweetgum half-sib seed source response to nitrogen and phosphorus fertilization in Mississippi. Soil Science Society of America Journal. 54: 871-878.

Nelson L.E.; Switzer, G.L. 1992. Response of nine-year-old plantation sweetgum to nitrogen fertilization in Mississippi. Southern Journal of Applied Forestry. 16: 146-150.

Robison, D.J.; Goldfarb, B.; Li, B. 1999. Advancing hardwood production forestry. PaperAge. May, 22-24.

Walters, M.B.; Reich, P.B. 1996. Are shade tolerance, survival, and growth linked? Low light and nitrogen effects on hardwood seedlings. Ecology, 77: 841-853.

Competition

Moderator:

JACK GNEGY
Westvaco Corporation

ADDITION OF SULFOMETURON METHYL TO FALL SITE PREPARATION TANK MIXES IMPROVES HERBACEOUS WEED CONTROL

A.W. Ezell[1]

Abstract— A total of 12 herbicide treatments were applied to a recently harvested forest site in Winston County, MS. All treatments were representative of forest site preparation tank mixtures and were applied early September, 1999. Three ounces of Oust7 were included in two of the tank mixes, and 19 ounces of Oustar7 were included in two of the mixes. All treatments were applied with a CO_2-powered backpack sprayer to simulate aerial application at 10 gpa. In May, June, July, and August of 2000, treatment plots were evaluated for herbaceous competition control. During October, 2000, plots were evaluated for woody stem control based on a comparison with pre-treatment measurements. In May 2000, herbaceous species had reduced the average percent clear ground to 42-62 percent in plots without Oust or Oustar while those plots with the products added had 94-97 percent clear ground. Untreated areas had only one percent clear ground by this rating time. Percent clear ground continued to decrease to 10-15 percent in July for plots without Oust or Oustar while plots were 83-94 percent clear in treatments with the product. By August, plots with the Oust were 65-80 percent clear and those with Oustar were 57-92 percent clear whereas plots without the products were 5-13 percent clear. Both Oust and Oustar provided excellent herbaceous weed control for 12 months following application in this study. Oustar provided slightly better control than the Oust.

INTRODUCTION

In establishing a new stand of trees, the competition from herbaceous weeds is a significant factor in the initial survival and growth of planted seedlings. The current conventional approach to this problem is to apply a release treatment over the top of the planted seedlings in either a broadcast or banded pattern. While this competition problem is most often addressed in pine management, it is a noteworthy in hardwood plantation establishment, also. Interest has been expressed in the potential for a site preparation treatment which would also provide first year herbaceous competition control for pine seedlings.

OBJECTIVES

The objectives for this study were as follows:

1) To evaluate the efficacy of Oust and Oustar for herbaceous weed control the year following site prepapplication.
2) To evaluate various tank mixtures for control of competing woody vegetation during site preparation

METHODS

The study was installed in Winston County, MS on land owned by The Timber Company. The previous stand had been mixed pine-hardwood and had been harvested in October, 1998. The soil was a clay loam with a pH = 5.6. A total of 12 herbicide treatments were applied on September 8, 1999. A complete list of the treatments is found in table 1.

Herbicide treatments were applied to with a CO_2-powered backpack sprayer with a total spray volume of 10 gpa. Each treatment and an untreated check were replicated three times in a completely randomized design.

Prior to treatment, a woody stem count was completed on each plot, and stems were recorded by species and height class. An ocular estimate of brownout was completed at 6WAT, and plots were assessed in October 2000 for any living woody stems. During May, June, July, and August, herbaceous cover was estimated ocularly in the plots. All data were subjected to ANOVA and specific tests to separate means.

RESULTS

The results of herbaceous competition control evaluations can be found in tables 2, 3, and 4. When compared to untreated areas, the herbicide treatments all exhibited control on herbaceous weeds. However, by July, those treatments without Oust or Oustar generally had 15 percent or less clear ground while those with Oust or Oustar generally had more than 80 percent clear ground (table 2). The addition of either Oust or Oustar provided excellent herbaceous weed control throughout the growing season.

Percent grass cover was relatively low on the area with scattered *Panicum* spp., *Carex* spp., and *Andropogon* accounting for the vast majority of this type vegetation. Only the *Andropogon* invaded the plots with Oust or Oustar (table 3). Overall, grass/sedge was not a major competitor on this site.

[1]Professor of Forestry, Department of Forestry, Mississippi State University, Mississippi State, MS 39762.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Broadleaf weeds were a major source of competition on this site. The site preparation mixes without Oust/Oustar did not differ from the untreated check in percent broadleaf coverage (table 4). The treatments with Oust or Oustar did an excellent job of controlling the broadleaves on this site until August which was 11 months after application. Even then, control was still good with generally less than 33 percent of the plot covered by broadleaves, although one replication in Treatment 11 did have higher infestation. The principal species on the site were fireweed (*Erechtites hieracifolia*), woolly croton (*Croton capitatus* var. *capitatus*), common ragweed (*Ambrosia artemisifolia*), and common pokeweed (*Phytolacca americana*). The woolly croton was not a problem until late in the growing season and accounts for much of the increased coverage in Oust/Oustar plots in August (table 4).

A wide variety of woody species occurred on this site, but the majority of stems were either sweetgum (*Liquidambar styraciflua*), red maple (*Acer rubrum*), or persimmon (*Diospyros virginiana*). There was no significant difference among any of the treatments in the control of sweetgum or persimmon, and only one treatment varied significantly in the control of red maple (table 5). Overall control of woody species was excellent as noted by the “Total” column in table 5. This percent is for all stems of all species. The more common of the “less frequent” species included loblolly pine (*Pinus taeda)*, winged elm (*Ulmus alata*), water oak (*Quercus nigra)*, cherrybark oak (*Q. pagoda)*, willow oak (*Q. phellos*), post oak (*Q. stellata*) and southern red oak (*Q. falcata*). Control for these species can be found in table 6. As might be expected, these species all generally increased their number of stems per acre in the untreated plots (table 5 and 6).

SUMMARY

Overall, the site preparation treatments in this study did an excellent job. The treatment areas were generally free of woody competition can could be planted easily.

Table 1—List of treatments in 1999 Fall Oust/Oustar site preparation field trials –MS

Treatment No.	Herbicides Rates/A.[a]
1	6 QTS KRENITE + 20 OZ CHOPPER + 1 QT TL90
2	4 QTS KRENITE + 20 OZ CHOPPER + 1 QT TL90
3	4 QTS KRENITE + 20 OZ CHOPPER + 1 QT TL90
4	4 QTS KRENITE + 16 OZ CHOPPER + 1 OZ ESCORT 1 QT TL90
5	4 QTS KRENITE + 20 OZ CHOPPER + 1 QT ACCORD SP + 1 QT TL90
6	5 QTS ACCORD SP + 16 OZ CHOPPER
7	1 QT ACCORD SP + 48 OZ CHOPPER + 1 QT TL90
8	1 QT ACCORD SP + 1 OZ ESCORT + 24 OZ CHOPER + 1 QT TL90
9	TMT #6 WITH 3 OZ OUST
10	TMT #7 WITH 3 OZ OUST
11	TMT #6 WITH 19 OZ OUSTAR
12	TMT #7 WITH 19 OZ OUSTAR
13	UNTREATED

[a] all rates are expressed as actual product.

The addition of Oust or Oustar to the treatments provided excellent herbaceous weed control for the entire growing season following application. Oustar did provide slightly better control than Oust, but this could be due to the species involved. Land managers now have an option for first year herbaceous competition control which could avoid release operations.

Table 2— Average percent clear ground in 1999 Fall Oust/Oustar site prep field trials-MS

	Time of Evaluation			
Treatment No.	May	June	July	August
	---------------Percent--------------------			
1	53b[a]	37b	10b	7c
2	42b	32b	13b	10c
3	62b	37b	18b	13c
4	42b	30b	13b	7c
5	53b	40b	15b	8c
6	47b	30b	10b	5c
7	43b	28b	10b	7c
8	58b	40b	13b	7c
9[b]	95a	91a	87a	80a
10[b]	97a	95a	93a	65b
11[c]	94a	90a	83a	57b
12[c]	96a	94a	94a	92a
13	2c	1c	0c	0c

[a.] Values in column followed by the same letter do not differ at P = 0.05
[b.] Treatments with 3 ounces Oust/A
[c.] Treatments with 19 ounces Oustar/A

Table 3-- Average percent grass cover in 1999 Fall Oust/Oustar field trials-MS

	Time of Evaluation			
Treatment No.	May	June	July	August
	-------------Percent--------------			
1	2	2	5	7
2	2	2	3	5
3	2	2	4	5
	4	2	2	3
5				
5	2	2	4	7
6	2	2	4	7
7	2	4	6	7
8	2	3	5	7
9[a]	0	0	0	1
10[b]	0	0	0	1
11[b]	0	0	0	1
12[b]	0	1	1	2
13	6	7	12	18

[a.] Treatments with 3 ounces Oust/A
[b.] Treatments with 19 ounces Oustar/A

Table 4-- Average percent bradleaf cover in 1999 Fall Oust/Oustar field trials-MS

Treatment No.	May	June	July	August
	Time of Evaluation			
	-------------------Percent---------------			
1	37b[a]	53b	67b	85b
2	50b	62b	68b	83b
3	43b	58b	67b	80b
4	53b	67b	70b	87b
5	43b	58b	67b	83b
6	53b	67b	75b	87b
7	57b	68b	78b	90b
8	40b	57b	67b	80b
9[b]	1a	2a	5a	20a
10[b]	1a	2a	2a	33ab
11[c]	2a	3a	6a	40ab
12[c]	1a	1a	2a	7a
13	50b	53b	53b	67b

[a.] Values in column followed by the same letter do not differ at P = 0.05

Table 6—Average percent stem reduction in "other" species found in 1999 Fall Oust field trials–MS

Trt. No.	LLP	WAD	WIE	CBO	WIO	POO	SRO
				Species[a]			
	--------------------------------Percent---------------------------------						
1	-100[b]	-100	+30	*	*	*	*
2	-100	-100	+85	-100	-100	-100	*
3	-100	-100	-46	-100	-100	-100	-100
4	*[c]	-100	-100	*	*	*	*
5	*	*	nc[d]	-85	*	-100	*
6	-100	*	-30	-100	-100	-100	-100
7	-23	*	-77	-100	*	*	-100
8	-58	-100	-100	-100	-100	-100	-100
9	-88	+100	-100	-100	-100	-100	-100
10	-10	-100	*	-100	-100	-100	-100
11	+33	+30	-89	-70	*	-57	*
12	-57	nc	-37	-100	-100	-100	-100
13	*	+700	+143	+30	nc	+31	+233

[a.] LLP = loblolly pine, WAO = water oak, WIE = winged elm, CBO = cherrybark oak, WIO = willow oak, POO = post oak, SRO = southern red oak
[b.] Negative values indicate reduction in number of stems
[c.] Insufficient stems for evaluation

Table 5— Average percent stem reduction of principal species in 1999 Fall Oust field trials-MS

Treatment No.	Herbicides[a]	SWG	REM	PER	Total
			Species[b c]		
		------------Percent--------------------			
1	Krenite + Chopper (6+20)	100a	-100a	-100a	-85ab
2	Krenite + Chopper (4+20)	-100a	-100a	-85ab	-90a
3	Krenite + Chopper (4+24)	-100a	-100a	-100a	-98a
4	Krenite + Chopper + Escort (4+16+1)	-100a	-100a	-100a	-94a
5	Krenite + Chopper + Accord SP (4+20+1)	-100a	-100a	-100a	-95a
6	Accord SP + Chopper (5+16)	-100a	-100a	-100a	-93a
7	Accord SP + Escort + Chopper (1+48)	-100a	-100a	-100a	-88a
8	Accord SP + Escort + Chopper (1+1+24)	-100a	-100a	-100a	-93a
9	Trt. #6 + 3 oz Oust/A	-89a	-100a	-100a	-93a
10	Trt. #7 + 19 oz Oust/A	-100a	-100a	-100a	-90a
11	Trt. #6 + 3 oz Oustar/A	-100a	-80b	-100a	-68b
12	Trt #7 + 19 oz Oustar/A	-100a	-100a	-100a	-94a
13	Untreated	+23b	+260c	+67c	+51

[a.] Krenite and Accord SP = quarts/A., Chopper and Escort = ounces/A.
[b.] SWG = sweetgum, REM = red maple, PER = persimmon
[c.] Values followed by the same letter in a column do not differ at P = 0.05

FIFTH-YEAR HEIGHT AND SURVIVAL OF LOBLOLLY PINE ACROSS TENNESSEE FOLLOWING VARIOUS SILVICULTURAL TREATMENTS

Lyle E. Taylor and John C. Rennie[1]

Abstract—Loblolly pine (*Pinus taeda*) was planted at nine experiment stations located across Tennessee in 1993-94 and 1994-95 using a customized fractional factorial design. Two sites, good and poor, were chosen on each experiment station to compare effects of soil productivity on height and survival. At each site, three treatments were evaluated: spacing (8X8, 8X10, and 10X10 feet), post-planting herbicide application after spring green-up (2.0 oz/ac Oust and 4.0 oz/ac Arsenal), and fertilization at planting (three, 9 gm, 22-8-2 fertilizer tablets per tree). Height measurements and survival counts were taken after the fifth growing season. The least square estimates of mean height and survival over all treatments and sites after five growing seasons were 11.9 feet and 83 percent, respectively. Results indicate that herbicide application increased tree height by 8 percent (11.4 vs. 12.4 feet). Survival increased 13 percent (77 vs. 87percent) when herbicide was used. Significant differences ($P < 0.05$) among experiment stations were found for height and for survival. Mean height estimates ranged from 9.5 feet at the West Tennessee Experiment Station to 13.5 feet at Ames Plantation and the Highland Rim Forestry Station. Survival ranged from 59 percent at the Dairy Experiment Station to 99 percent at the Highland Rim Forestry Station. No significant differences were found between good and poor sites. The herbicide treatment increased survival significantly more ($P < 0.05$) on poor sites than on good sites.

INTRODUCTION

The native range of loblolly pine (*Pinus taeda*) extends into only 13 of Tennessee's most southerly counties (see p. 497, Baker and Landgon 1990). However, it has been planted extensively in the state. These plantations were reflected in the number and distribution of U.S.D.A. Forest Service, Forest Inventory and Analysis plots with loblolly pine in the late 1980's (see p. 7, Beltz and Bertelson 1990). More evidence comes from the two most recent inventories of Tennessee's forest resources (table 1). The area of loblolly plantations was about 280,000 acres in the late eighties, increasing to about 385,000 acres in the late nineties (U.S.D.A. Forest Service 2001). The areas reported above are for loblolly pine, not loblolly-shortleaf pine as published in the state statistics. This increase of approximately 105,000 acres is about equally divided between forest industry and private non-industrial ownership. Thus, loblolly pine is an important species in Tennessee even though it has a limited native range in the state.

In the early 1990's, Dr. Edward Buckner and Mr. John Mullins of the University of Tennessee Department of Forestry, Wildlife and Fisheries, conceived a study to help Tennessee landowners more effectively grow loblolly pine. Specifically, this study was designed to determine the effects of various silvicultural treatments on the establishment and growth of loblolly pine on various sites commonly found in Tennessee.

METHODS

Tennessee has a wide range of growing conditions across its many diverse physiographic regions. For the results to be widely applicable, loblolly pine was planted at nine experiment stations located in five physiographic regions (figure 1). A good site and a poor site, based on the performance of agronomic crops, were chosen on each location (experiment station) to compare effects of soil productivity on height and survival. Only three sites were in forest cover immediately before study establishment: the good site and the poor site at the Forestry Experiment Station (Oak Ridge) and the poor site at Ames Plantation. The other sites had been in agriculture, including corn (2 sites), soybeans (2), alfalfa (2) and pasture (9).

Table 1—Area of Tennessee forests and of pure loblolly pine plantations in 1989 and 1999 (USDA Forest Service 2001)

	Area (thousands of acres)	
	1989	1999
Timberland	13,265	13,965
Loblolly plantations	280.2	385.6
Public	16.6	15.7
Forest Industry	184.6	235.4
Private non-industrial	79.0	134.5

Three treatments were evaluated: spacing (8X8, 8X10, and 10X10 feet), fertilization at planting (three, 9 gm, 22-8-2 fertilizer tablets per tree (22-8-2)), and post-planting

[1]Former Graduate Research Assistant (current address: 501 Fairways Dr., Apt. 7C, Vicksburg, MS) and Professor Emeritus, Department of Forestry, Wildlife and Fisheries, The University of Tennessee, Knoxville, Tennessee 37901-1071, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

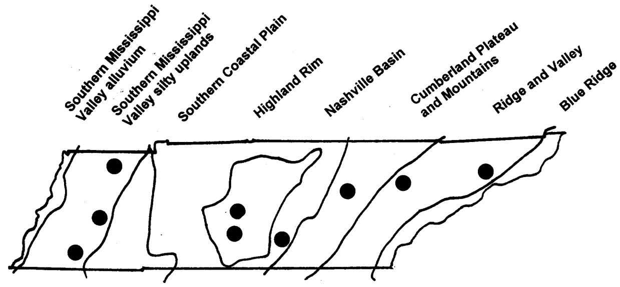


Figure 1—Physiographic regions of Tennessee and Agricultural Experiments Stations that served as study locations. In the Southern Mississippi Valley silty uplands from south to north, Ames Plantation (AMES), West Tennessee Experiment Station (WTES), and Martin Experiment Station; in the Nashville Basin from south to north, the Dairy Experiment Station (DES), and the Middle Tennessee Experiment Station (MTES); in the Highland Rim, the Highland Rim Forestry Station (HRFS); in the Cumberland Plateau and Mountains, the Plateau Experiment Station (PES); in the Ridge and Valley from west to east, the Forestry Experiment Station (FES) and the Tobacco Experiment Station (TES).

herbicide application after spring green-up (2.0 oz/ac Oust and 4.0 oz/ac Arsenal). The study was installed in 1993-94 and 1994-95 using a customized fractional factorial, incomplete block design. The first year's installations had nine plots per site, while in the second year there were 10 or 11 plots per site. Height and survival obtained after the fifth growing season are presented in this paper. A significance level of 0.05 was used. SAS PROC MIXED was used to analyze the data. Significant differences were tested using the PDIFF option.

RESULTS AND DISCUSSION

The least square estimates of survival and height over all treatments and sites after five growing seasons were 83 percent and 11.9 feet, respectively. Survival increased from 77 percent to 87 percent with herbicide application. Tree height increased from 11.4 feet to 12.4 feet when herbicide was used. Effects of herbicide on survival and height were statistically significant.

Significant differences among experiment stations were found for survival and for height. Survival ranged from 99 percent at the Highland Rim Forestry Station to 59 percent at the Dairy Experiment Station (figure 2). Survival at the Dairy Experiment Station was significantly lower than at all other sites. Most experiment stations had a small number of trees damaged by deer or winter weather. Damage due to snow and ice in the winter between the fourth and fifth growing season was more extreme at the Plateau Experiment Station. While 79.1 percent of the trees survived, only 59.2 percent were free of damage at this location.

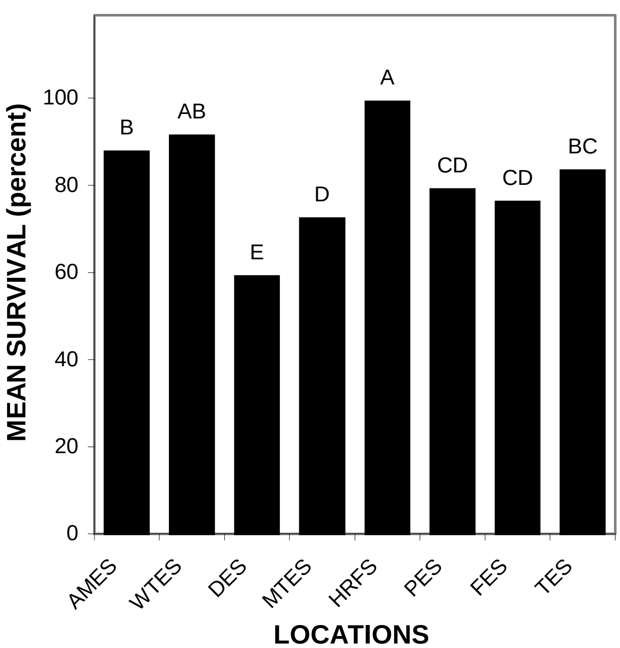


Figure 2— Least square estimates of mean survival for each location. Locations with the same letter were not significantly different (P > 0.05).

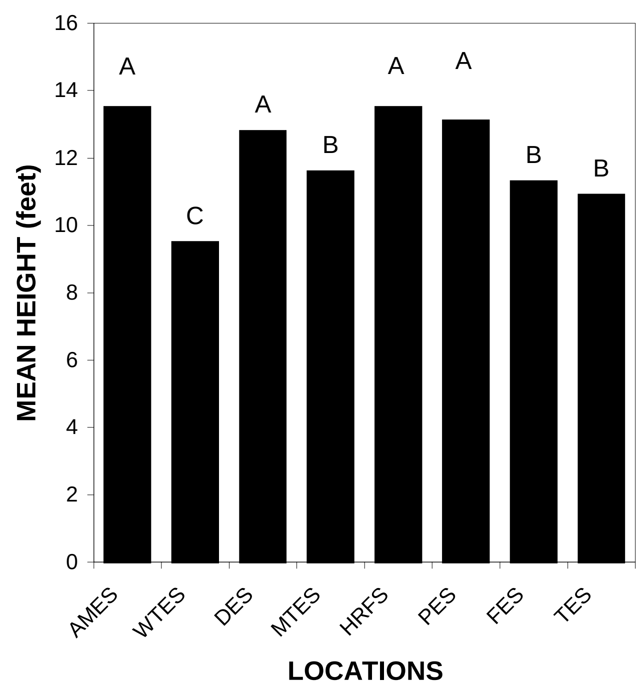


Figure 3— Least square estimates of mean height for each location. Locations with the same letter were not significantly different (P > 0.05).

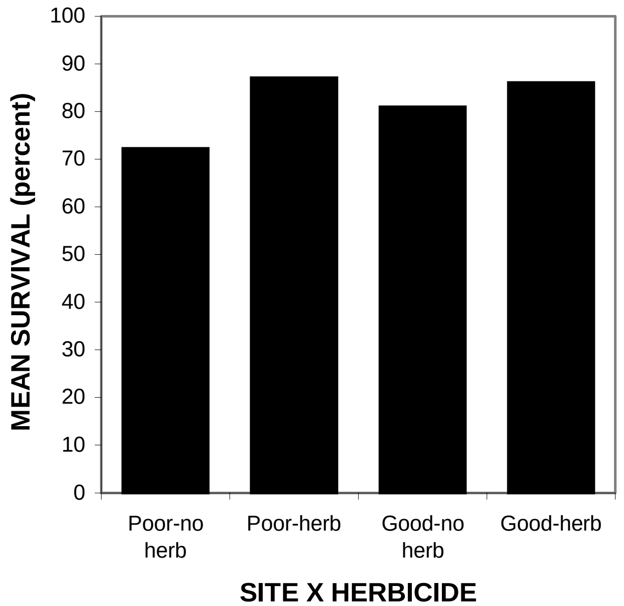


Figure 4— Least square estimates of mean survival for combinations of site and herbicide application.

Mean height estimates ranged from 13.5 feet at Ames Plantation and the Highland Rim Forestry Station to 9.5 feet at the West Tennessee Experiment Station (figure 3). Three nonoverlapping groups were found for height. Group one included Ames Plantation (13.5 feet), the Dairy Station (12.8), the Highland Rim Forestry Station (13.5) and the Plateau Station (13.1). Group two included the Middle Tennessee Station (11.6), the Forestry Station (11.3), and the Tobacco Station (10.9). Finally, group three consisted of only the West Tennessee Station (9.5). The height at the West Tennessee Station was low because the mean height for the poor site was only 6.5 feet. However, that for the good site was 12.5 feet.

The herbicide treatment increased survival significantly more on poor sites than on good sites (figure 4). Survival increased by 14.8 percentage points when herbicides were used on the poor sites as compared to an increase of 5.1 percentage points on the good sites. No such effect was found for height.

Although no significant differences were found between good and poor sites, some observations may be useful to others. Sites were selected and assigned to “good” or “poor” based on the performance of agronomic crops in consultation with the Superintendent of each experiment station. In the process of analyzing this study, we determined the soil type or types from soil surveys, and the loblolly pine site index and capability class based on soil type(s) for each site. There was little relationship between site index and capability class, and “good” or “poor” site. At two locations, the poor site had a higher site index than the good site, while at three locations both sites had the same site index. One site in the latter group was the Tobacco Experiment Station where survival and height were considerably higher on the poor site as compared to the good site.

RECOMMENDATIONS

Based on five years results, establishment and growth of loblolly pine can be successful throughout most of Tennessee. The treatment that showed promise for improving survival and height growth is the use of herbicides in association with planting. Their use on poor sites appears to have a greater effect on improving survival than on good sites. One factor limiting the success of loblolly pine is the occurrence of snow and ice frequently enough and in sufficient amounts to cause considerable mortality and damage.

REFERENCES

Baker, J.B.; Landgon, O.G. 1990. *Pinus taeda* L. Loblolly Pine. In: Burns, R.M.; Honkala, B.H., tech. coord. Silvics of North America, volume 1. Agriculture Handbook 654. Washington, D.C: U.S. Department of Agriculture, Forest Service: 497-512.

Beltz, R.C.; Bertelson, D.F. 1990. Distribution maps for Midsouth tree species. Resour. Bull. SO-151. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 56 p.

USDA Forest Service. 2001. Forest inventory and analysis data base retrieval system. <<http://www.srsfia.usfs.msstate.edu/scripts/ew.htm>> (March 2001).

THIRTEEN YEARS LOBLOLLY PINE GROWTH FOLLOWING MACHINE APPLICATION OF CUT-STUMP TREATMENT HERBICIDES FOR HARDWOOD STUMP-SPROUT CONTROL

Clyde G. Vidrine and John C. Adams[1]

Abstract—Thirteen year growth results of 1-0 out-planted loblolly pine seedlings on non-intensively prepared up-land mixed pine-hardwood sites receiving machine applied cut-stump treatment (CST) herbicides onto hardwood stumps at the time of harvesting is presented. Plantation pine growth shows significantly higher growth for pine in the CST treated plots compared to non-CST plots. Planted pine survival, diameter, height, stem-volume, and total volume per plot was higher in CST treated plots when compared to non-treated plots. Total pine volume in CST treated plots is as high as 125 percent higher than in non-treated plots. Pine growth advantage in CST treated plots has existed since time of planting. CST herbicides were selectively applied to the cut surface of hardwood stumps for stump-sprout control. The selective application of CST herbicides was combined with operation of a drive-to-tree type feller-buncher tree-harvester.

INTRODUCTION

Forest regeneration to pure pine stands after clearcut harvesting mixed pine-hardwood stands is a common forest management objective in the Southern United States. Competition from undesirable woody and herbaceous vegetation reduces pine survival and growth however. Pine volume after five years with competition control for both herbaceous vegetation and woody plants averaged about fourfold more than pine stands with no competition control for thirteen plantation study sites (Miller and others 1991). With only woody plant control pine volume increased by an average of 67 percent and with herbaceous control only pine volume increased by 171 percent. A significant portion of the woody competition may be hardwood occurrence from stump sprouting. Two conditions favorable for hardwood stump sprouting are low stump height and harvest of immature trees (Smith 1962). Those two conditions commonly result with mechanized harvesting using feller-buncher tree harvesters, especially when harvesting trees for pulp. Sprouts of hardwood stump origin are more vigorous than from seedling-origin (Smith 1979). Furthermore, the growth advantage of hardwoods of stump-sprout origin is maintained into later years (Smith 1962). After 12 yrs, diameter and height growth of stems of stump origin were almost twice that of stems from seedling origin for some hardwoods of seedling origin (Smith 1979). Vidrine and Adams (1993) reported hardwood stump sprouting had occurred on 67 percent of hardwood stumps two years after harvesting a mixed pine-hardwood stand. Vidrine also reported six year loblolly pine survival and growth results resulting from machine applied CST herbicides and the description of the sprayer system. Pine survival and growth in the CST plots were significantly higher than in control plots receiving no CST herbicides.

The sprayer system was adapted for use on a drive-to-tree type feller-buncher tree harvester to apply the CST herbicide immediately after cutting each hardwood tree. CST herbicides must be applied shortly after cutting to be effective (Wenger 1984). The sprayer system used in Vidrine's study consisted of an operator-controlled 12-volt direct current powered pump and full cone type spray nozzle with the nozzle mounted onto the feller-buncher harvester shear head. Immediately after shearing a hardwood tree the feller-buncher operator sprayed the cut stump surface using the sprayer system with a CST herbicide. This paper, using remeasured data from the same study as Vidrine, reports follow-up pine growth results after thirteen growing seasons as the stand nears the time for a first thinning harvest.

METHODS

The site is located in north central Louisiana in southern Lincoln Parish. Soils are Sacul (Aquic Hapludults) and Bowie (Plinthic Paleudults) silt loams with an estimated site index of 85 feet for loblolly pine at age 50 year (Kilpatrick and others 1996). The mixed pine-hardwood stand consisted of loblolly pine (*Pinus taeda L.*) and the hardwoods consisted principally of oak (*Quercu* spp), hickory (*Carya* spp), maple (*Acer* spp), and sweetgum (*Liquidambar styraciflua*). The site was clearcut harvested in July and August, 1985, with whole trees processed for fuel and pulp chips using an in-woods chipper, and replanted to pine the following winter. Trees were mechanically felled using a drive-to-tree type feller-buncher equipped with a double-acting shear head and whole tree skidding was performed using four-wheel-drive rubber-tired grapple skidders. Other than applying CST herbicide to hardwood stumps to control

[1] Professor of Forestry Mechanization and Professor of Forest Genetics, School of Forestry, Louisiana Tech University, Ruston, LA 71272, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

stump sprouting with the feller-buncher harvester, no mechanical, chemical, control burn, or other site preparation treatment was applied. The CST herbicides were machine applied at the time of felling while performing the clearcut harvest. Fifteen 0.2 ac CST test plots established consisted of three replicates of five treatments for the randomized block experimental design. The five CST treatments for the study consisted of a control (no CST herbicide applied), picloram (Tordon 101R), triclopyr-ester (Garlon 4), triclopyr-amine (Garlon 3A), and dicamba (Banvel CST)—all labeled for cut-stump-treatment. The freshly cut hardwood stump surfaces were machine-sprayed with one of the undiluted CST herbicides to include a thorough wetting of the cambial area in accordance with CST-label instructions. Bareroot 1-0 loblolly pine seedlings were outplanted in the 0.2-acre feller-buncher-sprayer treatment plots in February, 1986, on a 8 by 8-ft spacing using a 7 by 7 array for a total of 49 planted pines in each measurement plot of area 0.072 acre. Each planted pine was marked by a flagpin at the time of planting and at year ten aluminum tags were nailed to the remaining trees of the 49 originally planted. Tag labeling consisted of plot number, tree number, and the CST treatment. Performance evaluation of the process was based on 13-year growth measurements of pine total height, DBH, associated calculations of stem volume of individual trees, the resulting total planted pine volume in each plot determined by summing individual stem volumes, and hardwood stem count. Total tree volumes were calculated according to equations by Clark and Saucier (1990) from DBH and total tree height measurements. Duncan's New Multiple Range Procedure was used for mean separation for planted pine survival, height, diameter, stem volume, total volume in each plot, and number hardwoods present in each plot for the five-treatment three-replicate randomized block experimental design.

RESULTS AND DISCUSSION

Pine survival and growth on all machine-applied herbicide CST plots was significantly higher than pine growth on the control plots after thirteen growing seasons although there were differences within herbicide treatments (table 1).

Table 1—Planted pine survival, growth, and hardwood/volunteer pine competition of machine-planted DST herbicide treated plots after thirteen growing seasons[1]

	- - - - - - - - - - - Plot Means - - - - - - - - - - -						
Treatment	Survival (pct)	Ht. (ft)	DBH (in)	Stem Volume (ft^3)	Pine Volume (ft^3/ac)	Hardwoods (#/ac)	Volun. Pines (#/ac)
Picloram	77a	42a	6.3bc	3.9a	2030a	1240bc	429
Tri-a[2]	64abc	40bc	6.5ab	4.0a	1733ab	833d	371
Tri-e[3]	61bc	41b	6.7a	4.2a	1725ab	1181bcd	389
Dicamba	68ab	38c	6.2c	3.3b	1538b	2157ab	399
Control	46d	39c	5.6d	2.9b	904c	2343a	403

[1]Columnar means followed by the same letters are not significantly different at the 95-percent probability level, according to the Duncan's New Multiple Range Test.
[2]Tri-a is triclopyr amine
[3]Tri-e is triclopyr ester.

Mean number hardwoods and number of volunteer pines are also reported in table 1. Pine survival, height, and total pine volume were significantly higher in the picloram CST plots than other treatment plots. Pine diameter and stem volume were highest for the triclopyr-ester treated plots. Planted pine survival, height, diameter, stem volume and total plot volume were lowest in the control plots receiving no herbicide treatment to control hardwood stump sprouting. Mean total pine volume ranged from a low of 904 ft^3/acre in the control plots receiving no CST herbicide to a high of 2030 ft^3/acre for the picloram CST herbicide treatment. Plot volume, which accounts for the individual stem volumes and survival, was consistent with those factors. The inverse relationship between hardwood competition and pine growth reported by Langdon and Trousdell (1974) is supported by the results. Number of hardwood stems was the highest in the control plots at 2343 stems/acre with associated pine volume at 904 ft^3/acre while the picloram and triclopyr amine CST plot had the lowest hardwood stem count of 1240 and 833 stems/acre and the highest pine volume at 2030 and 1733 ft^3/acre, respectively. The dicamba plots had the highest hardwood stem count of the CST plots at 2157 stems/acre and lowest associated planted pine volume of the CST plots at 1538 ft^3/acre. There were almost as many volunteer pines on the plots as there were planted pine at thirteen years but the volunteer pine were generally smaller in diameter and height than the planted trees. Seed source of the volunteer pine was probably from the pines harvested at the time this study was established and from neighboring pine trees in the area. Statistical analysis was not applied to the mean number volunteer pines per plot since their occurrence was independent of the CST procedures applied. The occurrence of hardwood in the CST plots was generally not of stump sprout origin with the exception of the dicamba treatment. After two growing seasons, hardwood stump sprouting on picloram and triclopyr CST plots was only about 6 percent, while on the control plots stump sprouting was 67 percent, as reported by Vidrine and Adams (1993). Stump sprouting on the dicamba treated plots after two years was about 20 percent and may have contributed to the high number of hardwoods and low pine volume at age thirteen.

CONCLUSIONS

Results of this study indicate that machine application of CST herbicides during harvest to control hardwood stump sprouting is effective at suppressing hardwood competition thus allowing increased production of planted loblolly pine plantations. Pine volume on picloram treated plots was highest of all treatments at 2.25 times that of pine volume on non-CST treated plots after thirteen years growth. Pine volume was not significantly different for the picloram and the triclopyr treatments. Pine volume on the dicamba treated plots was lowest of the CST treatments but still 1.70 times that of the control plots. The 13-year results agree with the results from six-year growth, pine survival, diameter, and height in the picloram and triclopyr treated plots were significantly higher than for the other treatments (Vidrine and Adams 1993) indicating the benefits of the two CST treatments are maintained. Follow up studies of using machine applied CST herbicides for stump sprout control should be performed using sawhead equipped feller-bunchers as commonly used today rather than the shear type used in this study. Also, machine application techniques should be developed where the herbicide is applied only to the cambial area of the cut rather than wetting the entire cut surface to reduce the amount of herbicide required. For trees 3-inches dbh and larger, the recommended treatment area is the cambial area (USDA Forest Service 1994).

ACKNOWLEDGMENTS

This project was supported by the McIntire-Stennis Cooperative Forestry research program under Public Law 87-788. Plot sites were provided by Willamette Industries, Ruston, Louisiana. The herbicides triclopyr and picloram were furnished by Dow Chemical USA and dicamba by Velsicol Chemical Corp (now Sandoz Agro, Inc.).

REFERENCES

Clark, A; J.R. Saucier. 1990. Tables for estimating total-tree weights, and volumes of planted and natural southern pines in the southeast. Georgia Forest Research Paper no. 79. 23 p.

Kilpatrick, W.W.; C. Godfrey; C. Henry. 1996. Soil Survey of Lincoln Parish, Louisiana. U.S. Department of Agriculture, Natural Resources Conservation Service. 127 p.

Langdon, O.G.; K. Trousdell. 1974. Increasing growth and yield of natural loblolly pine by young stand management. P. 288-296 *in* Procceedings symposium on management of young pines, Williston, H.L.; W.E. Balmer, eds.. USDepartment of Agriculture, Forest Service Southeast, Area, State & Private For. and South. and Southeast. For. Exp. Stns. 349 p.

Miller, J.H.; Zutter, B.R.; Zedaker, S.M.; Edwards, M.B.; Haywood, J.D.; Newbold, R.A. 1991. A regional study on the influence of woody and herbaceous competition on early loblolly pine growth. Southern Journal Applied Forestry. 15: 169-178.

Smith, D.M. 1962. The practice of silviculture. New York: John Wiley & Sons: 517-518.

Smith, H.C. 1979. Natural regeneration and intensive cultural practices in Central Appalachian hardwood stands using clearcutting and selection cutting practices. In: Proceedings of the John S. Wright Forestry Conference. Lafayette, IN: Purdue University, West: 30-41.

USDA Forest Service, 1994. Pest and Pesticide Management on Southern Forests. R8-MB 60: U.S. Department of Agriculture, Forest Service, Southern Regional Management Bulletin. 46 p.

Vidrine, C.G.; J.C. Adams. 1993. Machine application of cut-stump-treatment herbicides. Applied Engineering in Agriculture. 9(2): 205-208.

Wenger, K.E. 1984. Forestry Handbook. New York: John Wiley & Sons. 1335 p.

WEED CONTROL AND SEEDLING PERFORMANCE USING OUST, VELPAR, AND VELPAR+OUST IMPREGNATED DIAMMONIUM PHOSPHATE

J.L. Yeiser[1]

Abstract—Technology that combines herbicide and fertilizer into one treatment thereby reducing application costs while enhancing growth is needed. Four clean and well-prepared sites in TX, MS, and AL were tested. Study objectives were to evaluate the effectiveness of diammonium phosphate (DAP) impregnated with Oust, Velpar, or Velpar+Oust for herbaceous weed control and newly planted loblolly pine (*Pinus taeda* L.) seedling growth. In 1999, treatments were applied early post weed-emergence to 60percent bare ground in East TX. Impregnated DAP provided about 38percent less competitor control than separate liquid and fertilizer applications at similar rates. Best seedling survival and growth resulted from liquid sprays of Oust and Velpar+Oust. Treatments in 2000 were applied to bare ground in TX, MS, and AL. Weed control for Oust-impregnated DAP, Velpar+Oust-impregnated DAP, Velpar impregnated on 250 pounds of DAP and liquid herbicide treatments was similar 120 days after treatment. Seedling survival and growth for impregnated DAP treatments was similar to that for conventional herbicide and DAP treatments. Growth trends are preliminary and will be followed. Drought probably influenced study results.

INTRODUCTION

Numerous studies spanning a variety of sites and conditions have demonstrated the effectiveness of vegetation management and fertilization at increasing loblolly pine growth. Consequently, the intensive culture of loblolly pine relies heavily on technologies of weed control and supplemental nutrition.

Currently, managers treat newly planted loblolly pine seedlings for herbaceous weed control and nutrient deficiencies in two separate applications and incur two application costs. Technology that combines multiple treatments, thereby reducing the number of passes and application costs per acre, is needed. The development of a weed-and-feed technology potentially combines two technologies, herbaceous weed control and fertilization, in a single application. The weed-and-feed approach has been tested in young pine stands less than three years old and other stands between ten and twenty-five years old (Shiver et al. 1999). Results suggest growth from the fertilizer impregnated with hexazinone (Velpar) was higher than either treatment separately as well as the untreated check. The usefulness of Oust, Velpar, and Velpar+Oust impregnated DAP applied over the top of newly planted seedlings needs to be tested. The purpose of this report is to present the weed control of liquid herbicide and herbicide impregnated DAP treatments and the resultant seedling growth. The objective of the 1999 test was to compare weed control and seedling performance among a post-emergence application of (1) conventional liquid herbicides, (2) the same conventional herbicides impregnated on 125 pounds of DAP, (3) 125 pounds of DAP only, and (4) neither herbicide nor DAP (Check). Specific rates of test treatments are presented in table 2. The objective of the 2000 study was to assess weed control and seedling performance among a pre-emergence application of (1) conventional liquid herbicides, (2) the same conventional herbicides impregnated on 125 or 250 pounds of DAP, (3) 125 pounds of DAP only, and (4) neither herbicide nor DAP (Check). Specific rates for test treatments are presented in tables 4 and 5.

METHODS

One location in 1999 and three locations in 2000 were tested. All four tests were clean of harvesting slash and free of established rootstocks. A summary of the sites is presented in table 1.

In TX, 1999 treatment plots were approximately 56 feet X 80 feet and consisted of seven trees in each of eight rows or 56 seedlings. In 2000, treatment plots were 64 feet X 80 feet with eight trees in each of eight rows or 64 seedlings. In MS and AL treatment plots were approximately 80 feet X 96 feet and spanned eight rows each with at least 10 seedlings. Treatment plots were surrounded by a 10 feet, untreated buffer strip.

[1]Professor and T.L.L. Temple Chair Arthur Temple College of Forestry Stephen F. Austin State University, Nacogdoches, TX 75962

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—A summary of test sites

Location	Beulah, TX	Diboll, TX	Picayune, MS	Whitfield, AL
Established	1999	2000	2000	2000
Physiography	UCP[a]	UCP[a]	LCP[a] flatwoods	LCP[a] interior flatwoods
Soil	silt loam	sandy loam	sandy clay loam	silty clay loam
Harvested	Dec-97	Sep-98	Dec-98	Aug-98
Site Prep1	9/98 Ars+Gar 4[b] 14oz+2qt	9/99 Ars+Gar 4[b] 16oz+2qt	10/99 shear & rake	12/98 burn
Site Prep2	10/98 burn	10/99 mulch	11/99 double bed	7/99 Chop+Esc+Acc[b] 40oz+1oz+1qt
Site Prep3	10/98 subsoil	10/99 subsoil	12/99 burn windrows	12/99 subsoil
Planted	Feb-99	Feb-00	Jan-00	Jan-00
Treated	22-Mar-99	9-Mar-00	16-Mar-00	3-Apr-00
Percent Cover	40	1	1	1
Treatments	Broadcast	Broadcast	Broadcast	Broadcast
Weed Emergence	Post	Pre	Pre	Pre

[a] UCP = upper coastal plain; LCP = lower coastal plain.
[b] Ars = Arsenal Ac; Gar 4 = Garlon 4; Chop = Chopper; Esc = Escort; Acc = Accord SP.

Measurement plots were internal to treatment plots. One row of buffer seedlings surrounded each measurement plot leaving 30 seedlings in 1999 and 36 seedlings in 2000 in each TX measurement plot. In MS and AL each measurement plot contained at least 50 measurement seedlings.

In 1999, all DAP treatments in TX were broadcast evenly by hand. In 2000, all DAP treatments in TX were applied with a cyclone seed sower. Plots were deliberately under-treated with the residual 15 percent applied by hand for a more even distribution.

Liquid treatments were applied with a "T" wand equipped with 4, 1101.5 TeeJet nozzles. Total application volume was 10 GPA.

Treatments were visually evaluated for percent control at 30, 60, 90 and 120 days after treatment (DAT). Control was expressed in 10 percent intervals with 0 = no control and 100 = total control. In 1999, individual species occupying at least 7 percent ground cover in all plots were evaluated separately. In 2000, diverse communities dominated plots. All herbaceous plants as a group were assessed for overall control.

For all sites, seedlings were assessed for survival (percent) and measured for height (cm) and ground line diameter (mm) prior to treatment and after one and two growing seasons. For analysis, height and ground line diameter data were converted to inches. Seedling volume was computed as volume index = $ht*gld^2$ and expressed in cubic inches.

The experimental design for all locations was a randomized complete block. The 1999 planting contained four blocks. All 2000 plantings had three blocks. An analysis of variance was conducted on survival, total height and volume index after one or two growing seasons. Duncan's New Multiple Range test P = 0.05) was used to separate treatment means.

Drought was severe during 1999 and 2000. All four tests were subject to uncommonly high temperatures and an extreme lack of moisture from July through October of 1999 and 2000.

RESULTS

1999 Post-Emergence Treatments

Liquid sprays and impregnated DAP provided similar control of purple cudweed (*Gamochaeta purpurea* (L.)Cabrera), a winter broadleaf, through 30 DAT (table 2). Small changes in control were observed 60 DAT. By 120 DAT, only 4 ounces of Oust impregnated on DAP provided similar control as liquid sprays. Impregnated DAP treatment provided an average of 14 percent less control of purple cudweed than liquid treatments 120 DAT. Liquid and impregnated treatments provided similar swamp sunflower (*Helianthus angustifolius* L.) control for 60 DAT; minor differences were detected 90 DAT. At 120 DAT, liquid spray exhibited more control than herbicide impregnated DAP treatments by an average of 24 percent. Differences in control of panicgrass (*Dichanthelium scoparium* (LAM.)Gould), *laxiflorum* (Lam.)Gould), and *acuminatum* (Sw.)Gould & C.A. Clark) and all species were detected 30 DAT and differences among treatment control continued to diverge with time. By 120 DAT, liquid sprays of Velpar+Oust and 4 ounces of Oust provided 43 percent better panicgrass control than 2 ounces of Oust and herbicides impregnated on DAP. Averaged across all species, herbicide-impregnated DAP provided 38 percent less control than liquid herbicides. Perhaps weed control could be improved with two modifications. First, a pre-emergence application activates herbicide in the soil for control of germinating weed seeds. Second, impregnating 250 rather than 125 pounds of DAP doubles the number of soil contact points for better coverage.

Major differences were detected in year-one seedling survival and growth (table 3). Best survival was achieved with liquid sprays of Velpar+Oust or Oust (4 ounces). Treatments of Oust alone (2 ounces) or herbicide impregnated DAP provided intermediate survival. Minor differences in total height were detected but all spray and impregnated DAP treatments provided similar seedling volume. Lowest survival and volume were recorded for the untreated check and DAP only plots. Fertilization without weed control resulted in lower survival than doing nothing (untreated check).

After two growing seasons, mean liquid and mean impregnated treatments exhibited 71 percent and 64 percent survival, respectively. Also, survival across all treatments had decreased an average of 7 percent below year one levels. Furthermore, seedling heights were commonly below 5 feet, illustrating the impact of two consecutive drought years. Volume index was greatest for liquid and impregnated treatments containing 2 ounces of Oust, both with and without Velpar. A fertilizer response was not detected although plots treated with DAP supported 66 cubic inches and unfertilized plots 56 cubic inches of volume - a difference of 10 cubic inches. This growth difference is expected to increase over time. Weed control provided 2.5 times more volume and fertilizer+weed control produced 2.9 times more volume than checks.

2000 Pre-Emergence Treatments

At all three sites, competitor control was similar for several liquid and impregnated treatments (table 4). Control was best 30 DAT and declined disproportionately by 120 DAT. For example, in TX, MS and AL, mean herbicidal control 30 DAT and 120 DAT was 97 and 95, 97 and 83, and 86 and 70 percent, respectively. Values reflect different weed pressure that may be related to soil moisture. Of the three sites, the TX site was the best drained (table 1), had the slowest weed re-invasion, and therefore the best long-term control. In contrast, the AL site had the poorest drainage, fastest weed re-invasion, and therefore the worst long-term control.

Seedling survival and growth for several herbicide-impregnated-DAP treatments was similar to conventional liquid and two-pass herbicide-fertilizer treatments at all three sites (table 5). Growth trends are very preliminary and will be followed over time.

All Four Sites

When considering all four sites, (1) 2 ounces of Oust followed with DAP (conventional two-pass treatments), (2) two ounces of Oust impregnated on 125 pounds of DAP, (3) two ounces of Oust impregnated on 250 pounds of DAP or 4 ounces of Oust impregnated on 125 pounds of DAP provided 89, 79, 83 and 83 percent control of weeds 120 DAT, respectively. Increasing the DAP rate from 125 to 250 pounds doubled the number of soil contact points and increased control 4 percent. Holding the DAP rate constant and increasing the Oust rate from 2 to 4 ounces increased control 4 percent. However, neither increasing the rate of DAP nor the rate of Oust significantly increase control. When comparing the Velpar+Oust mixture, the traditional liquid spray provided 91 percent and impregnated DAP 88 percent weed control 120 DAT. Velpar alone on 125 pounds of DAP provided 79 percent weed control, a level significantly less and 12 percent below the conventional liquid Velpar+Oust treatment. Increasing the number of contact points by impregnating 250 pounds of DAP increased weed control by 1 percent. The difference among the traditional liquid spray and Velpar impregnated on 250 pounds of DAP was 11 percent and not significant. Post-emergence liquid sprays of Velpar+Oust provided 85 percent weed control in contrast to 45 percent weed control for Velpar+Oust impregnated DAP. When the same treatments were applied pre-emergence, the conventional Velpar+Oust spray provided 90 and the impregnated DAP 89 percent control, a loss of 1 percent. Clean, well prepared sites promote product-soil contact and seed-originating competitors. For best results, managers contemplating this technology should commit to clean, well-prepared sites and early applications of impregnated DAP as a joint package.

CONCLUSIONS

On clean, well-prepared sites in TX, MS, and Al, pre-emergence applications of Oust, Velpar+Oust impregnated DAP, and Velpar impregnated on 250 pounds of DAP provided comparable herbaceous weed control 120 DAT as conventional liquid treatments of Oust or Velpar+Oust. Growth trends are very preliminary, with first- and second-year seedling survival and growth similar for liquid and herbicide-impregnated-DAP treatments and better than for checks. Managers interested in weeding-and-feeding seedlings at planting should consider levels of post-harvest biomass, intensive site preparation, and pre-emergence, herbicide-impregnated DAP treatments all part of an integrated package. Drought probably influenced study results.

Table 2—Control (percent) of unwanted herbaceous competitors with a March 22, 1999, early post-emergence application over the top of newly planted loblolly pine seedlings in East TX (Angelina County)

Treatments	Rate and formulation[a]		Days after treatment[b] 30	60	90	120
purple cudweed (*Gamochaeta purpurea* (L.)Cabrera)						
Velpar+Oust	1qt+2oz	S	100a	100a	100a	100a
V+O+DAP	1qt+2oz+125 lb	G	100a	95a	83ab	75b
Oust	4oz	S	100a	98a	98a	98a
Oust+DAP	4oz+125 lb	G	98a	97a	95a	95a
Oust	2oz	S	100a	97a	92ab	87ab
Oust+DAP	2oz+125 lb	G	90a	85b	75b	72b
DAP	125 lb	G	0c	0c	0c	0c
swamp sunflower (*Helianthus angustifolius* L.)						
Velpar+Oust	1qt+2oz	S	100a	100a	99a	99a
V+O+DAP	1qt+2oz+125 lb	G	93a	85a	83ab	63b
Oust	4oz	S	100a	100a	100a	99a
Oust+DAP	4oz+125 lb	G	99a	97a	85ab	85b
Oust	2oz	S	99a	98a	91a	91a
Oust+DAP	2oz+125 lb	G	83a	81a	70b	70b
DAP	125 lb	G	0b	0b	0c	0c
panicgrasses (*Dichanthelium* scoparium, *laxiflorum, acuminatum)*						
Velpar+Oust	1qt+2oz	S	100a	95a	95a	88a
V+O+DAP	1qt+2oz+125 lb	G	92b	85b	81b	38b
Oust	4oz	S	99a	96a	96a	92a
Oust+DAP	4oz+125 lb	G	92b	83bc	80bc	43b
Oust	2oz	S	98a	90a	83ab	60b
Oust+DAP	2oz+125 lb	G	85c	75c	73c	38b
DAP	125 lb	G	0d	0d	0d	0c
all species						
Velpar+Oust	1qt+2oz	S	95a	93a	89a	86a
V+O+DAP	1qt+2oz+125 lb	G	71bc	68b	46cd	45cd
Oust	4oz	S	86ab	80a	78ab	76b
Oust+DAP	4oz+125 lb	G	64c	60bc	38cd	36de
Oust	2oz	S	76bc	81a	60bc	55bc
Oust+DAP	2oz+125 lb	G	61c	50c	25d	21e
DAP	125 lb	G	0d	0d	0e	0f

[a] A single application of DAP. S = Liquid spray. G = Granule.

[b] Treatment means within a column sharing the same letter are not significantly different (Duncan's New Multiple Range test, P = 0.05 level).

Table 3—Treatments were applied near Beulah (Angelina County), TX on March 22, 1999 and loblolly pine seedling survival (S1, S2, pct), total height (H1, H2, inches) and total volume (V1, V2, in^3) determined after one and two growing seasons

Treatments[a]	Rate and formulation[b]		S1	H1	V1	S2	H2	V2
Velpar+Oust	1qt+2oz	S	87a	19.8ab	3.9a	79a	55.0ab	70.6a
V+O on DAP	1qt+2oz on 125 lb	G	73b	20.6a	3.8a	69abc	57.0a	76.0a
Oust	2oz	S	74b	18.0bc	3.7a	65bc	52.5ab	60.0ab
Oust on DAP	2oz on 125 lb	G	72b	21.5a	4.4a	65bc	55.9a	68.1ab
Oust	4oz	S	78ab	16.4c	3.1a	69ab	46.3d	40.1cd
Oust on DAP	4oz on 125 lb	G	68b	18.4bc	3.2a	58c	51.2bc	54.3bc
DAP	125 lb	G	28d	17.2c	1.6b	24e	47.2cd	25.8de
Check	None	-	40c	19.6ab	1.5b	38d	43.1d	22.6e

[a] Treatment means within a column sharing the same letter are not significantly different (Duncan's New Multiple Range test, P = 0.05 level).

[b] A single application of DAP. S = Liquid spray. G = Granule.

Table 4—Control (pct) of herbaceous weeds 30-120 days after pre-emergence (99 percent bare ground) treatment (DAT)

Treatment[a]	Rate and formulation[b]		30&60 DAT	90 DAT	120 DAT
Diboll, TX — Treated 9-Mar-00					
Oust	2oz	S	99a	98a	98a
Oust Then DAP	2oz & 125 lb	S;G	98a	98a	98a
Oust on DAP	2oz on 125 lb	G	89c	89a	91ab
Oust on DAP	2oz on 250 lb	G	99a	98a	98a
Oust on DAP	4oz on 125 lb	G	99a	98a	98a
Velpar+Oust	1qt+2oz	S	99a	98a	98a
V+O on DAP	1qt+2oz on 125 lb	G	98ab	98a	98a
Velpar on DAP	1qt on 125 lb	G	92bc	83ab	83b
Check	none		40d	40c	37c
DAP	125 lb	G	50d	45c	40d
Picayune, MS — Treated 16-Mar-00					
Velpar+Oust	1qt+2oz	S	99a	99a	97a
V+O on DAP	1qt+2oz+125 lb	G	99a	99a	85ab
Velpar on DAP	1qt+125 lb	G	96a	96a	67b
Velpar on DAP	1qt+250 lb	G	97a	68a	90ab
Oust	2oz	S	98a	59b[c]	38c[c]
Oust Then DAP	2oz & 125 lb	S;G	97a	97a	88ab
Oust Then DAP	2oz & 250 lb	S;G	97a	98a	85ab
Oust on DAP	2oz+125 lb	G	96a	96a	75ab
Oust on DAP	2oz+250 lb	G	97a	98a	85ab
Oust on DAP	4oz+125 lb	G	98a	98a	75ab
Check	None		45c	45b	5d
DAP	125 lb	G	57b	50b	7d
Whitfield,AL — Treated 3-April-00					
Velpar+Oust	1qt+2oz	S	93a	83a	75ab
V+O on DAP	1qt+2oz+125 lb	G	93a	81ab	77a
Velpar on DAP	1qt+125 lb	G	79c	74ab	70abc
Velpar on DAP	1qt+250 lb	G	81bc	74ab	70abc
Oust	2oz	S	90ab	83a	66bc
Oust Then DAP	2oz & 125 lb	S;G	90ab	83a	75ab
Oust Then DAP	2oz & 250 lb	S;G	76c	72b	66bc
Oust on DAP	2oz+125 lb	G	79c	72b	62c
Oust on DAP	2oz+250 lb	G	85abc	74ab	65bc
Oust on DAP	4oz+125 lb	G	90ab	78ab	73ab
Check	none		42e	39d	37d
DAP	125 lb	G	58d	49c	45d

[a] A single application of DAP. S = Liquid spray. G = Granule.
[b] Treatment means within a column sharing the same letter are not significantly different (Duncan's New Multiple Range test, P = 0.05 level).
[c] Heavy rainfall within one-hour of application may have influenced this value.

Table 5—Loblolly pine seedling survival (S1, pct) and growth (Height = H1, inches), Volume Index = V1, cubic inches) after one growing season

Treatment[a]	Rate and formulation[b]		S1	H1	V1
Diboll, TX					
Oust	2oz	S	92ab	22.4abc	7.7bc
Oust then DAP	2oz & 125 lb	S;G	94a	24.3a	9.4ab
Oust on DAP	2oz on 125 lb	G	85abc	21.2bc	8.2b
Oust on DAP	4oz on 125 lb	G	88abc	23.7ab	10.9a
Oust on DAP	2oz on 250 lb	G	82bcd	20.7c	7.9bc
Velpar+Oust	1qt+2oz	S	92ab	19.9c	7.4bc
V+O on DAP	1qt+2oz on 125 lb	G	83bc	19.6c	7.3bc
V on DAP	1qt & 125 lb	G	79cd	21.7abc	5.6cd
DAP	125 lb	G	46e	17.0d	2.1e
Check	None		73d	20.2c	3.6de
Whitfield, AL					
Oust	2oz	S	59ab	15.0e	2.8cd
Oust then DAP	2oz & 125 lb	S;G	69a	18.4ab	3.8ab
Oust then DAP	2oz & 250 lb	S;G	67ab	19.4a	4.4a
Oust on DAP	2oz on 125 lb	G	66ab	16.9bcd	2.4cd
Oust on DAP	4oz on 125 lb	G	57b	16.8cd	3.2bc
Oust on DAP	2oz on 250 lb	G	67ab	19.6a	4.4a
Velpar+Oust	1qt+2oz	S	57b	18.8a	4.5a
V+O on DAP	1qt+2oz on 125 lb	G	58ab	17.0bcd	3.2bc
V on DAP	1qt on 125 lb	G	63ab	16.7cd	2.7cd
V on DAP	1qt on 250 lb	G	68ab	18.5ab	3.3bc
DAP	125 lb	G	67ab	18.3abc	3.0bc
Check	None		65ab	16.6d	2.0d
Picayune, MS					
Oust	2oz	S	100a	21.8e	10.2e
Oust then DAP	2oz & 125 lb	S;G	100a	31.1bc	32.9b
Oust then DAP	2oz & 250 lb	S;G	99a	32.2b	39.8a
Oust on DAP	2oz on 125 lb	G	100a	30.2c	33.8b
Oust on DAP	4oz on 125 lb	G	100a	31.8b	28.5c
Oust on DAP	4oz on 250 lb	G	100a	30.3c	29.2c
Velpar+Oust	1qt+2oz	S	100a	31.5c	24.6d
V+O on DAP	1qt+2oz on 125 lb	G	100a	33.5a	33.2b
V on DAP	1qt on 125 lb	G	100a	27.5d	21.6d
V on DAP	1qt on 250 lb	G	100a	32.2b	38.1a
DAP	125 lb	G	100a	21.1ef	8.6e
Check	None		98b	20.2f	5.1f

[a] Treatment means within a column sharing the same letter are not significantly different (Duncan's New Multiple Range test, P = 0.05 level).
[b] A single application of DAP. S = Liquid spray. G = Granule.

REFERENCES

Shiver, B.D.; M. Link; B.M. Dial. . elpar impregnated fertili er: earl results of field trials. n: a ood, .D., ed. Proceedings of the Tenth biennial southern silvicultural research conference Februar 6 8, Shreveport, A. Gen. Tech. Rep. SRS 0. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 46 46 .

RESPONSE OF 1- TO 4-YEAR-OLD UPLAND HARDWOOD STANDS TO STOCKING AND SITE MANIPULATIONS

Jamie L. Schuler and Daniel J. Robison[1]

Abstract—The growth and development of very young natural even-aged hardwood stands is not well understood. The relative importance of biotic and abiotic constraints such as overstocking, herbaceous competition, tree nutrition, and pest impacts have not been widely studied in these types of stands. Earlier work has demonstrated significant tree growth response (2- to 20-fold) to release from these constraints. This paper will report on the continued measurement of these plots through year 4. Also, a new series of plots in 1 and 3 year old stands have been followed for 1.5 years. Treatments imposed include thinning, herbaceous competition control, fertilization, and combinations of these treatments. These experiments are beginning to show the potential of very early stand interventions to shorten rotation ages in upland hardwoods. These efforts are part of a broader set of initiatives across the South by the NC State Hardwood Research Cooperative to explore early interventions for stocking and competition control as a silvicultural option in managing hardwoods.

INTRODUCTION

The growth and development of very young natural even-aged hardwood stands is not well understood. While a general understanding of regeneration and self-thinning processes is accepted, the relative importance of biological constraints such as tree stocking, herbaceous competition, tree nutrition, and pest impacts have not been widely studied in these types of stands. Earlier work has demonstrated significant tree growth response (2- to 20-fold) to release from these constraints at ages 1 and 2 (Romagosa 1999, Romagosa and Robison 1999).

Southern hardwoods are often managed under an even-aged silvicultural system, with clearcutting prescribed as the regeneration method. Clearcutting commonly regenerates 25,000 - 100,000 stems/hectare. Given that current rotations for pulpwood and sawtimber at completion contain about 1000 and 250 harvestable stems/hectare, respectively, it seems apparent that 25,000 or more stems/hectare at establishment is well overstocked. This overstocking is often cited as a major factor constraining growth in forest stands. The numerous seedlings and sprouts from undesirable species retard the growth of more desirable species (Kays and others 1988).

A large number of thinning studies in young stands between 9 and 20 years of age were published, most with beneficial results (e.g. Heitzman and Nyland 1991, Johnson and others 1997, Pham 1985, Smith and Lamson 1983). However, the degree to which density affects growth at younger ages has not been quantified. Similarly, weed competition (herbaceous and woody) is known to seriously impede growth. This has been documented in plantations and natural stands for hardwood and coniferous species (e.g. Kolb and others 1989, Miller and others 1995, Nelson 1985, Romagosa and Robison 1999), but not evaluated fully within the control of other constraints.

Other biotic factors known to depress growth and prolong rotations include deer browse, and insect and fungal attack (Galford and others 1991, Korstian 1927, Marquis 1981). Experiments with deer exclosures through fencing and chemical repellants have demonstrated dramatic differences in height growth and species composition (Brenneman 1983, Marquis 1981). Stanosz (1994) used systemic pesticides to control insects and fungi on 1-year-old sugar maple (*Acer saccharum*) seedlings and had positive effects.

Tree nutrition has received much research attention, demonstrating the exceptional gains in productivity possible with fertilization (Allen and others 1990). Little nutrition research has focused on young hardwood stands outside of plantation culture. The few published studies show mixed results. Graney and Rogerson (1985), working with shelterwood regeneration, reported no effect of nitrogen fertilization on 5-year heights for oak seedlings, but increased white ash (*Fraxinus americana*) and cherry (*Prunus serotina*) 5-year heights. They cited extreme herbaceous competition exacerbated by fertilization as the cause. By contrast, significant responses to nitrogen and phosphorus were shown for 7 and 12 year old black cherry (*Prunus serotina*) stands in Pennsylvania (Auchmoody 1985) and 7 year old mixed hardwoods in North Carolina (Newton and others, this issue).

In the current study we report on the results of 2 studies. Both focused on factors constraining tree growth in very young (1 to 4 years old) naturally regenerated hardwood stands. In Experiment One, we report the 4-year effects of ameliorating weed competition and pest impacts for 2 years. In Experiment Two, we quantified the effects of overstocking, weed competition, and fertilization on very young upland hardwood stands.

[1]Graduate Research Assistant and Assistant Professor & Director of Hardwood Research Cooperative, Department of Forestry, North Carolina State University, 3118 Jordan Hall, Raleigh, NC 27695, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

METHODS

Experiment One

Experiment One was installed on three clearcut sites in the North Carolina Piedmont. The sites are located on 2 of the NC State University owned forests, the Schenck Memorial Forest (Wake County) and the Hill Forest (Durham County). Each site was salvage clearcut during the winter of 1996/97, prompted by hurricane Fran. The three sites have previously held stands of mixed pine-hardwoods, natural mixed hardwoods, and loblolly pine plantation. All sites have south-facing aspects and Cecil sandy loam soils on 2-10 percent slopes.

Four treatments were applied to 10 square meter square plots with 1 meter borders in a randomized complete block design with 4 replications. The treatments, applied during the growing seasons of 1997 and 1998 (years 1 and 2 after clearcutting), consisted of:

(1) Pesticide- an insecticide, fungicide, and mammal repellant sprayed periodically over the vegetation
(2) Weeded-hand shearing of all non-hardwood vegetation
(3) Full- pesticide and weeded treatments
(4) Untreated control

Due to space restrictions, site 1 had all four treatment plots, site 2 only treatments 3 and 4, and site 3 had treatments 1, 3, and 4. More detailed site and experimental design descriptions are contained in Romagosa and Robison (1999). The data reported include the 2 years when treatments were applied (age 1-2) and the 2 years after treatments were discontinued (age 3-4).

Experiment Two

Treatments were established on 2 upland North Carolina Piedmont sites. The Hill site (Hill Forest, Durham County), formerly a 2 hectare loblolly pine (*Pinus taeda*) stand with a small component of hardwoods, was clearcut logged in 1999. The Duke site (Duke Forest, Orange County), formerly a 5 hectare mature mixed oak (*Quercus sp.*) stand, was salvage clearcut in 1996/97 in response to damage from hurricane Fran. The Hill site has Cecil soils with undulating topography. The Duke site has Appling silt loam soils with a north-facing aspect on 2-10 percent slopes.

Ten square meter circular plots with 1 meter borders were randomly located, insofar as each plot contained at least 2 yellow-poplar (*Liriodendron tulipifera*) and 2 oak trees. Each site contained a total of 8 treatments replicated in 4 blocks. The treatments were begun in July 1999 and continue to the present. The treatments were installed in a 2x2x2 factorial design with the main factors being:

(1) Weeded vs. unweeded- hand removal of all non-arborescent vegetation
(2) Fertilized vs. unfertilized- 90 kilograms/hectare of nitrogen and 100 kilograms/hectare of phosphorus applied as diammonium phosphate
(3) Thinned vs. unthinned-stem density reduced to 4 stems/plot, consisting of 2 yellow-poplar and 2 oak trees

The data reported for Experiment Two focus on the 5 most dominant yellow-poplar in each of the unthinned plots and the 2 yellow-poplars in each thinned plot. Therefore, the data represented a total of 8 stems on thinned and 20 on unthinned plots. This was done to reduce the error associated with different species composition among treatments and blocks. Yellow-poplar was selected for comparison because it represents an important timber species in the region, it existed in all plots, and as a fast-growing shade intolerant species it provides a rapid measure of treatment effects.

Table 1—Density and growth response for 3 (1997) and 4 (1998)-year-old hardwood and pine seedlings in Experiment One (see text for description) averaged across three upland North Carolina Piedmont sites. Pines had been removed from the weeded and full study plots during years 1 and 2

		Stem Count (No./10 m^2)		Basal Diameter (mm)		Total Height (cm)	
Treatment	Species	1999	2000	1999	2000	1999	2000
Control	hardwood	163	163	8.7	11.8	61	107
	Pine	146	193	13.2**	20.0**	78**	131**
Pesticide	hardwood	60	60	8.7	12.7	64	113
	pine	178	196	11.8**	19.7**	76*	137**
Weeded	hardwood	163	153	14.0	17.2	85	116
	pine	0	0	-	-	-	-
Full	hardwood	353	376	16.3	18.9	110	145**
	pine	0	7	-	1.4	-	14

Significant differences between hardwood and pine seedlings within each treatment/year pair are designated by * for alpha = 0.1 and ** for alpha = 0.05. Stem count data were not analyzed for differences. Pesticide treated plots received a combination of pesticides only, weeded plots had all non-hardwood vegetation removed, and the full treatment was pesticide + weeded. Treatments were applied during years 1 and 2, then discontinued.

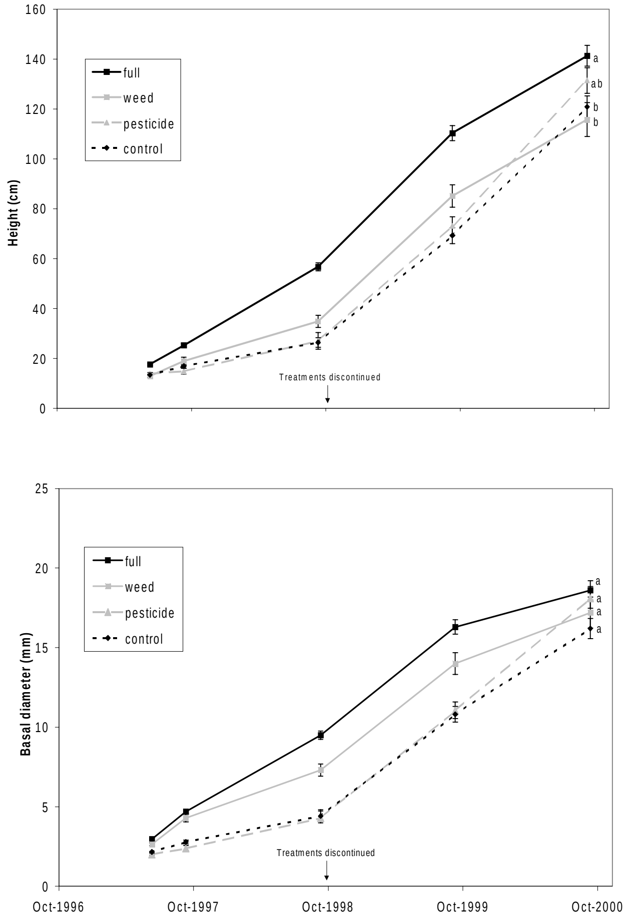


Figure 1—Mean height (top) and basal diameter (bottom) (3 sites, 8-12 plots per treatment) of natural regeneration following winter 1996/97 clearcutting on NC upland Piedmont sites. Different letters indicate statistical differences at alpha = 0.05 using ANOVA protected LSD means separation procedure. The arrow indicates the time when treatments were discounted.

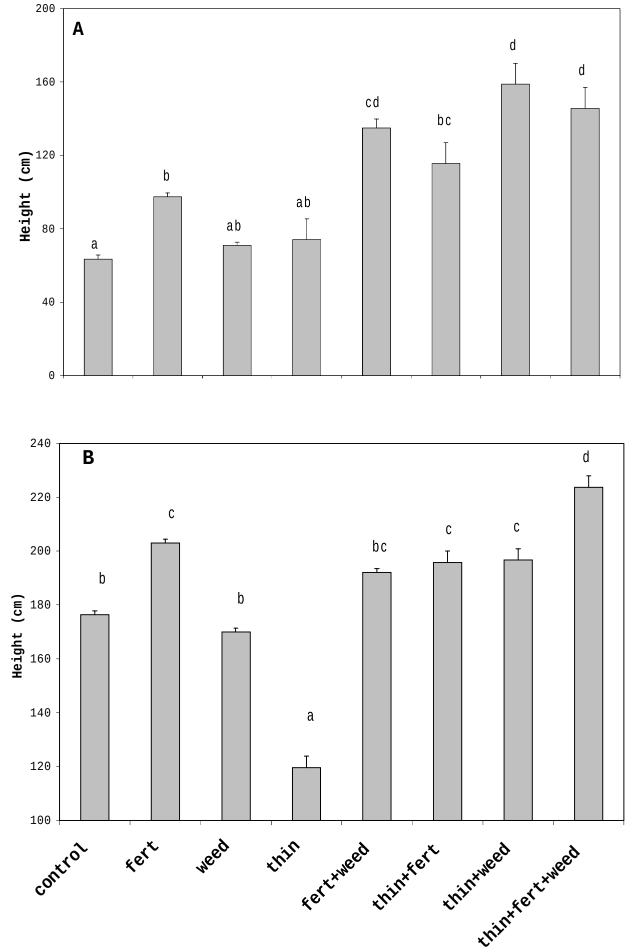


Figure 2—Mean (+/-SE) height of dominant yellow-poplar at age 2 (1.5 years of treatment) at the Hill Forest (a, top), and at age 4 (1.5 years of treatment) at the Duke forest (b, bottom). Different letters indicate statistical differences at alpha = 0.05 using ANOVA protected LSD means separation procedure.

RESULTS AND DISCUSSION

Experiment One

Romagosa and Robison (1999) reported substantial and significant gains attributed to weeding and full treatments for the first 2 years of treatment. After 4 years of growth (treatments were applied during the initial 2 years) the full treatment still has greater cumulative heights and diameters, but significant differences ($P < 0.05$) only occurred for height growth (figure 1). By year 4, the pesticide and control treatments marginally surpassed the weeded treatments in height and diameter growth. These trends suggest convergence among treatments.

However, the application of the treatments inadvertently complicated the study. For the weeded and full treatments, all non-hardwood vegetation, including pine trees, were periodically sheared for 2 years. As a result, we are seeing the effects of loblolly pine on the control and pesticide treated plots (where they were not removed) beginning to out compete the hardwood seedlings on these shallow Cecil soils with southerly-facing slopes. On the control and pesticide treated plots at the end of year 4, loblolly pine accounted for roughly 50 and 75 percent of the stem count, respectively. By the end of the 4th growing season (2000), the loblolly pine component was accumulating more diameter and height growth than the hardwoods (table 1). By examining the curves in figure 1, and either mentally factoring pines into the full and weeded plots, or factoring them out of the pesticide and control plots, the trends do suggest a continuing positive effect of the treatments.

Experiment Two

Initial height measurements were significantly different ($P<0.05$) among treatments for both sites. Therefore, the 2000 cumulative height data were adjusted using initial height as a covariate.

Fertilization significantly improved yellow-poplar height growth (+ 54 percent) after 1.5 years on the 2-year-old Hill site (figure 2a). The combination of fertilization + weeding showed a positive interaction ($P = 0.0791$), as did thinning

+ weeding (P = 0.0587). Results suggest that weeds compete more strongly than seedlings with the dominant yellow-poplar trees. However, when both competitors were removed large gains in height growth were observed.

Fertilization significantly enhanced yellow-poplar height growth (+15 percent) after 1.5 years, on the 4-year-old Duke site (figure 2b). Again, weeding and thinning treatments had no measurable positive effect on dominant yellow-poplar height growth. Fertilization out performed all other treatments except for the combined effects of thinning + fertilization + weeding. We surmise that the availability of nutrients became limiting on this site as tree seedlings and other vegetation competed for the similar resources. Even when thinning, weeding, and fertilization treatments are combined, the yellow-poplar trees only grew 10 percent more than for fertilization alone.

CONCLUSIONS

The objectives of this work were to determine if early stand interventions could be used to identify factors that constrain productivity on upland Piedmont sites. Both experiments demonstrate the potential of early silvicultural treatments to accelerate growth and possibly reduce rotation lengths.

The 4-year results (through age 4) from Experiment One suggest that early gains are sustainable even after treatments are discontinued. Full treatments have maintained a growth advantage over all other treatments.

In Experiment Two, both the 1- and 3-year-old stands responded well to fertilization after 1.5 years. Thinning and weeding treatments suggest that at very early ages weed competition is more severe than competition from other seedlings, at least for dominant yellow-poplar seedlings. Thinning and weeding showed synergistic effects when combined together.

ACKNOWLEDGMENTS

Mark Romagosa initiated Experiment One and graciously provided the first 2 years of data. The authors thank Jim Bridges, Judson Edeburn, David Gadd, Robert Jetton, Leslie Newton, and David Nishida for their assistance with these studies, and the NC State University Hardwood Research Cooperative members for supporting this work.

REFERENCES

Allen, H.L.; P.M. Dougherty; R.G. Campbell. 1990. Manipulation of water and nutrients-practice and opportunity in southeastern U.S. pine forests. Forest Ecology and Management 30: 437-453.

Auchmoody, L.R. 1982. Response of young black cherry stands to fertilization *Prunus serotina*, Pennsylvania. Canadian Journal Forest Research 12 (2): 319-325.

Brenneman, R. 1983. Impact of deer on forest regeneration. In: Proc. Regenerating forest stands. 1983 Penn State forestry issues conference, University Park, PA: 126-132.

Graney, D.L.; T.L. Rogerson. 1985. Development of oak, ash and cherry reproduction following thinning and fertilization of upland hardwood stands in the Boston Mountains of Arkansas. In: Shoulders, E., ed. Proceedings of the Third biennial southern silvicultural research conference; 1984 November 7-8, Atlanta, GA. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 171-177.

Heitzman, E.; R.D. Nyland, 1991. Cleaning and early crop-tree release in northern hardwood stands: a review. Northern Journal of Applied Forestry. 8(3): 111-115.

Johnson, J.E.; J.J. Bollig; R.A. Rathfon. 1997. Growth response of young yellow-poplar to release and fertilization. Southern Journal of Applied Forestry. 21(4): 175-179.

Kays, J.S.; D.W. Smith; S.M. Zedaker; R.E. Kreh. 1988. Factors affecting natural hardwood regeneration of Piedmont hardwoods. Southern Journal of Applied Forestry. 12(2): 98-101.

Kolb, T.E., T.W. Bowersox, L.H. McCormick, K.C. Steiner. 1989. Effects of shade and herbaceous vegetation on first-year germination and growth of direct-seeded northern red oak, white ash, white pine, and yellow-poplar. Gen. Tech. Rep. NC-132: U.S. Department of Agriculture. Forest Service.

Korstian, C.F. 1927. Factors controlling germination and early survival in oaks. Bull. 19. New Haven, CT: Yale University School of Forestry. 115 p.

Marquis, D.A. 1981. Effect of deer browsing on timber production in Allegheny hardwood forests of northwestern Pennsylvania. Res. Pap. NE- 475: U.S. Department of Agriculture. Forest Service.

Miller, J.H.; B.R. Zutter; M. Zedaker; M.B. Edwards; R.A. Newbold. 1995. Early plant succession in loblolly pine plantations as affected by vegetation management. Southern Journal of Applied Forestry. 19(3): 109-126.

Nelson, E.A. 1985. Weed control and fertilization aid sweetgum plantation establishment. In: Proceedings of the Fifth Central Hardwood Forest Conference: 68-70.

Pham, C.H. 1985. Thinning of young hardwood regeneration in southeastern West Virginia. In: Proceedings of the Fifth Central Hardwood Forest Conference: 25-33.

Romagosa, M.A. 1999. An evaluation of the biological constraints to the early growth of hardwoods on North Carolina Piedmont clearcuts. Raleigh, NC: NC State University. M.S. Thesis. 102 p.

Romagosa, M.A.; D.J. Robison. 1999. An evaluation of biological constraints to the early growth of natural hardwood regeneration on North Carolina Piedmont clearcuts. In: Haywood, J.D., ed. Proceedings of the Tenth biennial southern silvicultural research conference; 1999 February 16-18, Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 39-42

Smith, H.C.; N.I. Lamson. 1983. Precommercial crop-tree release increases diameter growth of Appalachian hardwood saplings. Res. Note NE-534: U.S. Department of Agriculture. Forest Service. Res. Note NE-534.

Stanosz, G.R. 1994. Benomyl and acephate applications increase survival; of sugar maple seedlings during their first growing season in northern Pennsylvania. Canadian Journal of Forest Research. 24: 1107-1111.

ACCELERATING PLANTED GREEN ASH ESTABLISHMENT ON AN ABANDONED SOYBEAN FIELD

John W. Groninger and Didier A. Babassana[1]

Abstract–Planted green ash seedlings exhibit high survival rates on most bottomland sites that have recently come out of row crop production, making this species a popular choice for afforestation. Sub-optimal growth of planted hardwood tree species, including green ash, often delays the realization of many of the economic and environmental benefits that are used to justify the expense of tree planting and land use conversion. This study evaluates the impacts of silvicultural treatments, including pre-planting discing, and two herbicide treatments (sulfometuron and glyphosate) on early stand development in a green ash planting on a former soybean field in southern Illinois. After two growing seasons, both herbicide treatments increased green ash height growth while tillage produced no response. Sulfometuron increased total cover and percent grass cover relative to glyphosate and unherbicided treatments, largely by stimulating the growth of broomsedge (Andropogon virginicus). Glyphosate doubled broadleaf cover relative to the sulfometuron and no herbicide treatments.

INTRODUCTION

Formerly-forested bottomland sites offer excellent opportunities for afforestation in the lower Midwest and Mid-south. Typicaly, these sites were cleared of forest cover during the soybean boom of the 1960's and 70's but are now considered marginal for row crop agriculture. More recently, private and government programs are resulting in restoration of native hardwood cover to many of these sites (Stanturf and others 2000).

While survival and growth of planted trees is usually adequate to satisfy afforestation guidelines, the combination of planted trees and volunteer vegetation have failed to produce forest cover in some areas. Establishment failures in similar settings have been attributed to poor matching of species and site (Hodges 1997). Sometimes, these conditions are an unintended consequence of long-term row crop agriculture and may ultimately limit the number of desirable species that are suitable for the site. Green ash (Fraxinus pennsylvanica Marsh.) is one species with demonstrated utility in formerly farmed bottomland sites and was therefore selected for use in this study (Groninger and others 2000).

Competition from herbaceous vegetation also appears to hamper the establishment of canopy cover on similar sites. Funds are generally available through cost share programs for vegetation control treatments, including tillage and herbicides. However, their use is limited because several local land managers question the value of these treatments. The objectives of this study were to evaluate the efficacy of tillage and herbicide treatments, alone and in combination on the establishment of planted green ash. Further, volunteer herbaceous vegetation response to these treatments were evaluated.

METHODS

This study was conducted on a poorly drained site in Saline County, Illinois. Soils were classified as a Bonnie silt-loam (Fine-silty, mixed, acid, mesic, Typic Fluvaquents). The site had been cleared of forest cover ca. 1967 and cropped periodically thereafter in soybeans. Corn was planted in 1997 and the site left fallow in 1998. In Fall 1998, the site was mowed and enrolled in the Wetlands Reserve Program.

The tilled treatments consisted of a) three passes with a tandem disk drawn by a 40 hp farm tractor and b) an untilled control. Tillage was carried out on May 8, 1999, the earliest date soil moisture conditions permitted use of this equipment. Herbicide treatments consisted of a) sulfometuron methyl, b) glyphosate, and c) an untreated control.

Green ash seedlings (1-0) of unknown origin were obtained from the Illinois State Tree Nursery. Seedlings were machine planted on May 4 with follow-up hand planting to replace mis-planted individuals on May 28. Immediately following replacement planting, herbicide treatments were initiated. Sulfometuron was applied over the top using an ATV mounted with a 10 foot boom as 2 oz Oust/ac. in a water carrier. At that time, budbreak had occurred in some seedlings. The glyphosate treatment was applied on July 8 as 1.5 percent RoundupPro solution using a water carrier. The glyphosate treatment was applied to a 4.5 foot diameter circle around each seedling. During the glyphosate application, seedlings were shielded with a 4" diameter stovepipe to prevent herbicide contact with foliage.

Seedling survival and height were measured during the winter following the first and second growing season. Deer

[1]Assistant Professor of Silviculture and former Graduate Student, Department of Forestry, Southern Illinois University, Carbondale, IL 62901-4411, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Mean end of growing season height for planted green ash in response to competition control treatments. Means within a column followed by the same letter are not significantly different (á < 0.05)

Treatment	Year 1	Year 2
	----------Height(inches) ---------	
No herbicide	14a	26a
Glyphosate	20b	39b
Sulfometuron	18b	40b

Table 2—Predominant volunteer vegetation across competition control treatments during the second growing season

Species	Cover (percent)
Crabgrass (Digitaria sanguinalis)	22
Broomsedge(Andropogon virginicus)	13
Barnyard grass(Echinochloa crusgalli)	7
Goldenrod (Solidago spp.)	4
Horseweed(Conyza canadensis)	3
Trumpet creeper(Campsis radicans)	2
Yellow nutsedge(Cyperus esculentus)	2

Table 3—Second-year volunteer vegetation response to competition control treatments. Means within a column followed by the same letter are not significantly different (< 0.05)

	Broadleaves	Grasses	Total cover
	--------------percent--------------		
No herbicide	11 a	31 a	42 a
Glyphosate	24 b	33 a	57 a
Sulfometuron	11 a	66 b	77 b

and rodent damage were assessed immediately prior to bud break preceding the second growing season. Identity and percent cover of each herbaceous species were determined during early August within a 0.5 m^2 area surrounding each planted seedling.

The study employed a randomized split plot design where main plots consisted of tillage treatments and split plots consisted of the herbicide treatments. Each experimental unit consisted of 20 green ash seedlings. The study was replicated four times with blocks intended to account for soil moisture conditions. Significant differences between treatments were identified using Duncan's New Multiple Range Test (< 0.05). Tree height and cover data were

Table 4—Second-year broomsedge and horseweed cover response to competition control treatments. Means within herbicide and tillage within a column followed by the same letter are not significantly different (< 0.05)

Treatment		Broomsedge	Horseweed
		----Cover (percent)----	
Herbicide	No herbicide	8 a	3 a
	Glyphosate	5 a	11 a
	Sulfometuron	27 b	7 a
Tillage	No tillage	22 b	3 b
	Tillage	5 a	11 a

transformed using logarithmic and arc sine transformations, respectively.

RESULTS AND DISCUSSION

Green ash survival at the end of two growing seasons exceeded 95 percent in all treatments and was not considered in further analyses.

Tree growth

Green ash height was greater in response to herbicide treatments following both the first and second growing seasons (table 1). Herbicide treatments did not differ from one another in terms of growth response despite the fact that the pre-emergence sulfometuron application resulted in a longer period of nearly total weed control than the post-emergence glyphosate treatment.

Seedlings showed evidence of foliar damage, including chlorosis and small leaf size, in response to sulfometuron application (Babassana 2000). Ezell and Catchot (1997) and Horsley and others (1992) reported similar damage in response to post-foliation application of sulfometuron at similar rates. Although herbicide damage did not impact survival rate, resources that might have otherwise increased height growth were needed to overcome herbicide-induced injury. An unusually dry late spring may have also played a role in eliminating competition control gains associated with the earlier weed control treatment.

The tillage treatment did not effect seedling growth, consistent with the findings of Kennedy (1985). Successful tillage operations appear to require multiple treatments at least through the first growing season (Devine and others 2000).

Deer browsing between the first and second growing seasons was minimal (< 3 percent across treatments) which may reflect a particularly mild winter or the relative unpalatability of green ash seedlings (Rayburn and Barkalow 1973). Deer browse will be assessed immeidately prior to the third growing season, following a particularly long and cold winter.

Volunteer Vegetation

Volunteer community composition during the second growing season was typical of an abandoned bottomland field in this region (Bazzaz 1968) dominated by native and exotic grass and forb species (table 2). Volunteer community composition differed in response to herbicide treatments (table 3). Glyphosate more than doubled percent cover of broadleaf weeds over the other herbicide treatments. Sulfometuron resulted in 100 percent greater grass cover relative to glyphosate and the control. Overall, sulfometuron resulted in the highest average percent vegetation cover, driven largely by increased broomsedge cover (table 4). Tillage generally did not impact cover of dominant weed species. Exceptions were broomsedge which was decreased by tillage and horseweed which was increased by tillage.

Increased broomsedge dominance in response to weed control has been widely observed (Miller and others 1995). The antagonistic effects of broomsedge on first-year growth of trees is well-documented (Morris and others 1989; Zutter and others 1999). In the present study, broomsedge is becoming dominant somewhat later in stand development and may therefore impact tree growth differently. In the present study, the two herbicide treatments resulted in differing community composition but result in virtually identical tree growth. In this setting, the apparently increasing importance of broomsedge should provide some information regarding the role of post-establishment community composition on green ash growth in the coming years.

CONCLUSIONS

After two growing seasons, herbicides, but not tillage, improve green ash height growth. The amount and composition of volunteer vegetation differed among herbicide treatments providing land managers with the flexibility to establish a range of herbaceous community types while simultaneously accelerating tree canopy closure. Further monitoring will be required to determine the effects of these treatments on long-term vegetation development.

ACKNOWLEDGMENTS

This study was funded by the McIntire-Stennis Cooperative Forestry Program and the Shawnee R. C. and D. Special thanks to David Allen of the Illinois Department of Natural Resources for aiding in the design and implementation of this study and Dr. Mike York and his family for graciously allowing us use of their land.

REFERENCES

Babassana, D. A. 2000. Establishing a green ash plantation using mechanical and chemical site preparation. Unpublished M.S. Thesis, Southern Illinois University at Carbondale. 63 p.

Bazzaz, F. H. 1968. Succession on abandoned fields in the Shawnee Hills, southern Illinois. Ecology 49: 924-936.

Devine, W. D.; A. E. Houston; D. D. Tyler. 2000. Growth of three hardwood species through 18 years on a former agricultural bottomland. Southern Journal of Applied Forestry 24: 159-165.

Ezell, A. W.; A. L. Catchot, Jr. 1997. Competition control for hardwood plantation establishment. In: Waldrop, Thomas A., ed. Proceedings of the 9th biennial southern silviculture research conference; 1997 February 25-27; Clemson, SC. Gen. Tech. Rep. SRS-20, Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 42-43.

Groninger, J. W.; W. M. Aust; M. Miwa; J. A. Stanturf. 2000. Growth predictions for tree species planted on marginal soybean lands in the Lower Mississippi Valley. Journal of Soil and Water Conservation 55(1): 91-95.

Hodges, J. D. 1997. Development and ecology of bottomland hardwood sites. Forest Ecology and Management 90: 117-125.

Horsley, S. B.; L. H. McCormick; J. W. Groninger. 1992. Effects of timing of Oust application on survival of hardwood seedlings. Northern Journal of Applied Forestry 9: 22-27.

Kennedy, H.E. Jr. Cultural treatments influence hardwood growth and foliar nutrient concentration on a minor stream bottom site. Research Paper SO-215. New Orleans, LA: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 6 p.

Miller, J. H.; B. R. Zutter; S. M. Zedaker; M. B. Edwards; R. A. Newbold. 1995. Early plant succession in loblolly pine plantations as affected by vegetation management. Southern Journal of Applied Forestry 19: 109-126.

Morris, L. A.; S. A. Moss; W. S. Garbett. 1989. Competitive interference between selected herbaceous and woody plants and Pinus taeda L. during two growing seasons following planting. Forest Science 39: 166-187.

Rayburn, W. A.; F. S. Barkalow, Jr. 1973. Seasonal deer browse preference for tupelo and green ash. Journal of Forestry 71: 31-33.

Stanturf, J. A.; E. S. Gardiner; P. B. Hamel; M. S. Devall; T. D. Leininger; M. E. Warren, Jr. 2000. Restoring bottomland hardwood ecosystems in the lower Mississippi Alluvial Valley. Journal of Forestry. 98(8) 10-16.

Zutter, B. R.; G. R. Glover; R. J. Mitchell; D. H. Gjerstad. 1999. Sweetgum and broomsedge response to competition across a range of organic matter during the first year of plant establishment. Forest Science 45:423-432.

HERBACEOUS WEED CONTROL IMPROVES SURVIVAL OF PLANTED SHUMARD OAK SEEDLINGS

A.W. Ezell and J.D. Hodges[1]

Abstract—Shumard oak seedlings were planted on a cutoversite in the Mississippi River floodplain, which had received both chemical and mechanical site preparation treatments. Soil at the site was a commerce silt loam and the elevation was such that the area does not flood. Planting stock was 1-0, bareroot seedlings. A total of seven active herbicide treatments were applied at a preemergent timing over the top of the planted seedlings prior to the onset of the 1998 growing season. In addition, an untreated check was established and all treatments were replicated three times. Each plot consisted of 200 linear feet of planted row with 20 seedlings. Seedlings were tagged and flagged for measurement purposes. Competition control was evaluated at 30, 60, 90 and 150 days after treatment. At each evaluation timing, the seedlings were evaluated for any symptoms of herbicide damage. In November of 1998 and 1999, seedling survival was recorded. Overall, herbaceous competition control significantly increased seedling survival. Differences exist among treatments and between year of observation. Without herbaceous competition control, seedling survival and plantation establishment may be questionable in areas of severe weed pressure.

INTRODUCTION

Thousands of acres are being planted with hardwood species in the South each year. These hardwood seedlings cost more than pine seedlings and planting costs are typically greater for hardwoods. Higher planting costs combined with longer rotation lengths combine to create a scenario in which high survival rates are essential to improve the cost-efficiency of the planting operation.

Unfortunately, survival in many of these planting efforts has been less than desirable (James 2000). The lack of desirable survival rates has been especially true of the oak species planted. In oak planting, initial survival is principally dependent upon three factors: seedling quality, planting quality, and competition control (or the lack thereof). For optimal results in oak plantings, larger, rigorous seedlings must be handled and planted properly, and the herbaceous competition should be controlled for at least a portion of the first growing season (Ezell 2000). Depending on the site, species planted, and growing conditions during the first year following planting, the control of competing vegetation con improve oak seedling survival from an appreciable amount (20 percent) to what could be considered a critical amount (80 percent or greater) (Ezell and Catchot 1997, Ezell 2000).

MATERIALS AND METHODS

Study Site

The study was installed on land owned by Anderson-Tully Company in Bolivar County, MS. The site is in the Mississippi River floodplain but does not flood, and the soil series across the area is a commerce silt loam. The stand had been harvested in 1997 with a complete removal of all merchantable stems, and an aerial application of herbicide was applied late in the growing season of 1997 to control residual undesirable woody vegetation. The area was hand planted with 1-0, bareroot Shumard oak seedlings in January 1998.

Treatments

On March 18, 1998, a total of seven herbicide treatments were applied to the planted area. These applications are considered preemergent in reference to the fact that the oak seedlings had not visibly broken dormancy (no bad swelling, bad break, etc.). A complete list of treatments is found in table 1.

All treatments were applied over-the-tops of the planted oak seedlings as a banded treatment. Each treatment band was a 6-foot wide spray swath, which had the planted oaks as the center of the band. All treatments were replicated three times in a randomized complete black design. Each treatment plot was a linear area 200 feet long, which contained a minimum of 16 oak seedlings. All treatments were applied using a CO_2 powered backpack sprayer with a TK 2.5 Floodjet nozzle on a hand-held wand, which delivered a total spray volume of 20 gallons per acre at a pressure setting of 30 psi.

Seedling Measurements

Each oak seedling in the treatment plots were identified by placing a pin flag carrying a permanent number aluminum tag approximately two inches from the base of the seedling. This permanent number identified the seedling to facilitate consistency of data recording and comparison of data from different evaluation times. Initial height (centimeters) and groundline diameter (millimeter) were recorded for each seedling.

[1]Professors of Forestry, Mississippi State University, Mississippi State, MS 39762

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—List of treatments applied in Shumard oak study

Treatment No.	Herbicide (rate per acre)[a]
1	2 oz Oust
2	64 oz Goal 2XL
3	5.6 oz Scepter 70DG
4	96 oz Goal 2XL
5	64 oz Goal + 5.6 oz Scepter 70DG
6	2.8 oz Pursuit DG
7	2.8 oz Pursuit DG + 5.6 oz Scepter 70DG
8	Untreated check

[a] All rates are expressed in amount of product per acre

Table 2—Average survival of Shumard oak seedlings in treatment plots

Survival Treatment No.	1998	1999
	Percent	
1	69.4b[a]	63.9b
2	80.6a	80.6a
3	63.9b	70.8b
4	86.1a	66.7b
5	91.7a	80.6a
6	66.7b	58.3bc
7	52.8c	47.2c
8	77.8ab	44.4c

[a] Values followed by the same letter do not differ at P=0.05

Plot Evaluation

All treatment plots were evaluated at 30, 60, 90, 120 and 150 days after treatment (DAT) for an assessment of herbaceous competition control and any symptomology of herbicide impact on the seedlings. In November 1998 and October 1999, seedling survival was recorded for each treatment plot. Competition control was recorded as percent clear ground with attention given to the principal species across the study area and any species, which occurred in the treatment plots.

RESULTS

At the end of the first growing season, only 3 of the herbicide treatments had an average survival, which was greater than the untreated plots (table 2). Overall survival across all plots was less than observed responses in other studies (Ezell 2000) and 2 factors are given credit for the lack of a positive treatment response and lower overall survival. First, the study site experienced severe drought conditions during the growing season, and it is probable that the shading provided by the competition may have benefited the seedlings in the untreated areas. Second, herbivory by deer was greater in the treated plots, as the open areas created by the treatment bands facilitated the movement of the animals and they occasionally browsed the seedlings as they moved through the area. While this type of herbivory done would probably not have resulted in overt mortality, it may have been a factor in weakening seedlings, which were also stressed by the droughty conditions.

At no time during the evaluations did any of the seedlings exhibit any symptoms of herbicide damage. Thus, the mortality can not be related to a lack of crop tolerance, and these products can be considered safe to use on Shumard oak as they were applied in this study, Even though first year survival was not as high as desirable, all treatments had acceptable survival except Trt. #7 and while 52.8 percent survival would result in marginally sufficient stocking for management, greater survival is expected when herbaceous weeds are controlled following proper plating operations.

Survival at the end of the second growing season provided interesting results. Generally average survival was slightly lower for treatments with 2 exceptions. Survival in Trt. #3 (5.6 oz of Sceptor 70 dg) was actually higher at the end of the second season than was recorded after the first growing season. This was due to resprouting of seedlings, which were necrotic from ground level and above in 1998 and were recorded as mortality at that time. Widely scattered occurrence of this resprouting was noted in other treatments, but not to the extent as found in Trt. #3 plots.

Survival in the untreated plots (Trt. #8) was drastically reduced at the end of the second growing season (table 2). The overall reduction of 77.8 percent (1998) to 44.4 percent (1999) represents a 43 percent change in these areas and was representative of what was occurring across the larger operational area outside the research plots. While the competing vegetation may have provided some shading during the first growing season, it also established a root system, which competed for any available soil moisture. While no indices of competing vegetation were undertaken in 1999, it seems that the trees in the treated plots were better able to establish a root system during the first growing season and were subsequently better able to compete for soil moisture during 1999. Land managers would do well to note that first year survival of planted oak seedlings in areas not receiving herbaceous competition control may not be indicative of “final establishment” survival.

SUMMARY

Six of the 7 herbicide treatments resulted in average survival, which was significantly greater than the untreated areas by the end of the second growing season. None of the treatments caused any damage to any oak seedlings and are considered safe to use. However, as of 2001, only OUST® and Goal 2XL® have labels for operational applications as were conducted in this study. Good seedlings and proper planting will always be important factors in obtaining desirable levels of initial survival of planted oak seedlings, and herbaceous weed control can result in significant benefits. Without herbaceous weed control, the cost and effort of properly planting high quality oak seedlings may not be enough to achieve desirable survival rates.

REFERENCES

Ezell, A.W. 2000. Companion of Sulfometuron Methyl Formations for use in Nuttall and Cherrybark Oak Plantations. In. Proc. Of 53rd South. Weed Sci. Soc. Ann. M&Q 53:108-109.

Ezell, A.W; A.L. Catchot, Jr. 1997. Preemergent and Postemergent Applications of Sulfometuron Methyl for Competition Control in Oak Plantations. In: Proc. Of 50th South. Weed. Sci. Soc. Ann. M&Q 50:109-112.

James, J. 2000. Unpublished Master's thesis. Dept. of Forestry. Mississippi State University.

RESPONSE OF PLANTED ROYAL PAULOWNIA TO WEED CONTROL TREATMENTS AFTER COPPICE

David O. Mitchem, James E. Johnson, and Richard E. Kreh[1]

Abstract—Today there is an increased interest in growing royal paulownia (*Paulownia tomentosa*) in the southeastern United States, but difficulties have been encountered in the Piedmont due to heavy clays and intense competition for moisture. Two royal paulownia plantations were established on the Virginia Piedmont to evaluate the effects that weed-mats have on tree survival and growth. The trees with weed-mats on the first plantation, an upland site, had 28 percent greater survival, were 2.8 feet taller, and had .9 inch greater diameter at breast height (dbh) at 4 years after coppice than the trees with no weed-mats. The trees with weed-mats on the second plantation, a bottomland site, had 10 percent greater survival, were 1.6 feet taller, and had .2 inch greater dbh at 4 years after coppice than the trees with no weed-mats.

INTRODUCTION

Today, there is growing interest in growing and managing paulownia plantations in the southeastern United States (Kays and others 1998). Royal paulownia (*Paulownia tomentosa*)is a pioneer species that was introduced into the United States approximately 160 years ago (Hu 1959). Royal paulownia is also known as the kiri tree, empress tree, and the princess tree. Paulownia wood is light in color, has a low density, and dries quickly without warping or cracking. Royal paulownia is easy to recognize by its large heart shaped leaves, its purple flowers, and large number of seed-pods present in mature trees. This tree is known for its rapid growth and ability to grow on a variety of sites. However, difficulties have been encountered in the Piedmont due to heavy clay soils and intense competition for moisture. Site preparation treatments can be used to break up the heavy clay soils, while herbicide and/or weed-mats can be used to control competition. The purpose of this study is to quantify the effects that weed-mats have on royal paulownia growth and survival in the Virginia Piedmont.

METHODS

In the spring of 1994, two royal paulownia plantations were installed near Virginia Tech's Reynolds Homestead Forest Resources Research Center located in the Piedmont physiographic province in Patrick County, VA. One plantation was on an upland (ridge-top) site, while the other was located on a bottomland site (floodplain). Each site was bedded before planting. Soil samples were collected from each plantation for characterization purposes. Ten push tube samples of the top 10 inches were collected and composited for each plantation. The soils were air dried and ground to pass a 2 mm sieve. The soils were then analyzed for total nitrogen and total carbon. Particle size analysis and pH were also determined. Containerized seedlings were planted in the spring of 1994. A 3ft by 3ft weed-mat was put around half of the trees at each site, while the other half were untreated. Herbicide applications of a 1.5 percent solution of glyphosate were applied around all trees each year. The trees were coppiced in the spring of 1997 after 3 growing seasons. Tree survival, tree heights, and diameters were recorded each November for five years (1996-2000). Weed-mat treatment effects on ground line diameter (GLD), height, diameter at breast height (DBH), and volume were analyzed by t-tests at the .10 level.

RESULTS AND DISCUSSION

Soil Characterization

Soil chemical and physical properties for both sites are presented in table 1. The upland site had a much higher coarse fragment content and a higher clay percentage than the bottomland site. The bottomland site has much higher levels of nitrogen and organic matter than the upland site. Sites with clay contents greater than 30 percent should be

Table 1—Soil chemical and physical properties for the upland and bottomland sites in Patrick County, VA

Site properties	Upland	Bottomland
Coarse fragment(%)	41	3
Sand(%)	39	38
Silt(%)	27	48
Clay(%)	34	14
Textural class	clay loam	loam
pH	5.31	5.67
Total N(ppm)	783	1338
Estimated N(lbs/ac)	1355	3222
Organic matter(%)	1.90	2.89

[1]Research Specialist, College of Natural Resources, Department of Forestry (0324), Virginia Tech, Blacksburg, VA 24061; Professor of Forestry and Associate Dean - Outreach; Senior Research Associate and Superintendent, Reynolds Homestead Forest Resources Research Center, PO Box 70, Critz, VA 24082, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 2-–Royal paulownia seedling performance for the upland site in Patrick County, VA

Variable	Treatment	Year[a] 1996	1997	1998	1999	2000
Survival(percent)	Weed-mat	51	51	50	50	50
	No weed-mat	23	23	23	23	22
GLD (in)	Weed-mat	2.4a	1.9a	8.5a	4.4a	5.3a
	No weed-mat	1.9b	1.6b	6.6b	3.4a	4.4a
DBH (in)	Weed-mat				3.1a	3.8a
	No weed-mat				2.6b	2.9b
Height (ft)	Weed-mat		7.5a	14.2a	19.6a	23.6a
	No weed-ma		6.2b	11.8a	16.7a	20.8a
Volume (ft^3)	Weed-mat		0.24a	1.4a	1.5a	2.7a
	No weed-mat		0.19a	0.9a	1.0a	2.0a

[a] Means within a column followed by the same letter are not significantly different at the 0.10 level.

Table 3-–Royal paulownia seedling performance for the bottomland site in Patrick County, VA

Variable	Treatment	Year[a] 1996	1997	1998	1999	2000
Survival(percent)	Weed-mat	55	55	46	40	37
	No weed-mat	40	40	36	32	27
GLD (in)	Weed-mat	2.2a	1.4a	2.2a	2.8a	3.5a
	No weed-mat	2.1a	1.3a	1.9b	2.4b	3.0b
DBH (in)	Weed-mat				2.0a	2.4a
	No weed-mat				1.8b	2.2a
Height (ft)	Weed-mat		5.6a	10.7a	13.8a	15.4a
	No weed-mat		5.2a	14.2a	12.8a	13.8a
Volume (ft^3)	Weed-mat		0.15a	0.56a	0.56a	0.89a
	No weed-mat		0.12a	0.44a	0.44a	0.69a

[a] Means within a column followed by the same letter are not significantly different at the 0.10 level.

avoided for paulownia plantations (Kays and others 1998), but site preparation treatments such as bedding or trenching can be used to ameliorate the effects of heavy clays by providing an improved rooting medium. The upland site is more typical of abandoned agricultural land in the Piedmont that would be planted to paulownia.

Seedling Performance

Seedling survival and growth were measured for five growing seasons, 1996 to 2000. Variables measured include percent survival, ground-line diameter (GLD), diameter at breast height (DBH), total height, and seedling volume expressed as diameter squared times height. In 1996, only GLD and survival data was collected. The 1999 growing season was the first year that DBH data was collected.

Upland Site—The means for the upland site are presented in table 2. The trees with weed-mats had 50 percent survival in the year before coppice, while the trees without weed-mats had only 23 percent survival (table 2). Survival did not vary substantially after the third growing season. Royal paulownia is highly dependent on adequate soil moisture for rapid growth (Beckjord 1991). Factors that influenced survival at this site were drought, late frosts, and disease. The weed-mats reduced competing vegetation, and thereby conserved water. High competition for moisture gave the trees with weed-mats an advantage which may have lessened the damage done by late frosts and disease.

Significant differences in GLD's were found for 1996, 1997, 1998, but not for 1999 and 2000. However, significant differences for DBH's were found for 1999 and 2000 suggesting that early GLD response leads to increased DBH growth in later years. In the fourth year after coppice (2000), the mean DBH was 0.9 inches larger for trees with weed-mats (table 2). A significant difference in height was found for only the first year after coppice, but 4 years after coppice the mean height was 2.8 feet taller for trees with weed-mats(table 2). No significant differences were found for volumes. Four years after coppice, the trees with weed-mats had 35 percent greater volume than trees without weed-mats.

Bottomland Site—The means for the bottomland site are presented in table 3. Tree survival slowly declined from 1997 to 2000. This site initially had higher survival than the upland site, but was more prone to multiple late spring frosts and deer damage. Late frosts killed back initial flushes at least once each year. Deer damage at this site included girdling the trees, as well as breaking the stem in some cases. The trees with weed-mats had 37 percent survival while trees without weed-mats had only 27 percent survival at four years after coppice (table 3). This site is a good example of how important site selection is when considering planting royal paulownia. The soils at this site would indicate royal paulownia should grow very well, but due to its topographic position and susceptibility to frost damage, this was a poor site selection.

Significant differences in GLD's were found for 1998,1999, and 2000. In addition, DBH's were found to be significantly different for 1999, but not for 2000. In the fourth year after coppice (2000), the mean DBH was .2 inches larger for trees with weed-mats (table 3). No significant differences were found for tree heights or volumes. However, trees with weed-mats were 1.6 feet taller and had 29 percent more volume than trees without weed-mats.

CONCLUSION

The establishment of a royal paulownia plantation on the Virginia Piedmont can best be described as difficult. On these sites, late frosts, drought, disease, and deer damage reduced overall survival and growth. This study does however suggest that weed-mats are beneficial and improve tree survival and growth. The trees with weed-mats on the upland site had DBH's that were 31 percent larger, heights 13 percent greater, and a survival rate that was more than twice that for trees having no weed-mats. The trees with weed-mats on the bottomland site had DBH's that were 9 percent larger, heights 12 percent greater, and survival that was 10 percent greater than the trees without weed-mats. Weed-mats can be a useful tool for the establishment of a productive royal paulownia plantation.

REFERENCES

Beckjord, P.R. 1991. Preliminary spacing trials of *Paulownia tomentosa*. Tree Planters' Notes 34: 34-35.

Hu, S.-Y. 1959. A monograph of the genus Paulownia. Quarterly Journal Taiwan Museum 12(1-2): 1-53.

Kays, J., D. Johnson; J.W. Stringer. 1998. How to produce and market paulownia. Univ. of Maryland Coop. Ext. Serv. Bull. 319. College Park, MD. 22 p.

Pine Natural Regeneration

Moderator:

NANCY HERBERT
USDA Forest Service

THE PLANTATION CONVERSION DEMONSTRATION AT THE CROSSETT EXPERIMENTAL FOREST—IMPLICATIONS FOR CONVERTING STANDS FROM EVEN-AGED TO UNEVEN-AGED STRUCTURE

James M. Guldin and Robert M. Farrar, Jr.[1]

Abstract—In the absence of replicated studies, we used a case study demonstration to illustrate converting a 26-year-old even-aged loblolly pine (*Pinus taeda* L.) plantation to uneven-aged structure. Unreplicated treatments included maintaining even-aged structure through low thinning (thinning from below) to a residual basal area of 80 square feet per acre, and two methods of converting to uneven-aged structure-one using the volume control guiding diameter limit method, and the other using the BDq method of structural regulation. Over 12 years, all three treatments had a periodic annual increment of over 90 square feet per acre in both total merchantable and sawtimber cubic volume; all three treatments also maintained annual sawtimber volume growth rates of 90-100 square feet per acre, 450-600 board feet per acre Doyle rule, and 600-750 board feet per acre International ¼-inch rule. In all volume increment measurements, the even-aged treatment exceeded the volume control method, which exceeded the BDq method. Conversely, the BDq method was the only treatment in which adequate pine regeneration was established and making acceptable development; regeneration development in the volume control treatment was marginal, and it was unacceptable in the even-aged treatment. After 12 years, residual basal area levels exceeded 60, 75, and 100 square feet per acre in the BDq, volume control, and even-aged treatments, respectively. To increase the reliable development of regeneration in these treatments, lower residual basal areas should be considered.

INTRODUCTION

Over the past two decades, interest has grown in converting even-aged stands to uneven-aged structure. A public forest land manager or a private forest landowner might consider this conversion because uneven-aged stands have more heterogeneous within-stand habitat and structural attributes than plantations. Examples include enhanced vegetation or wildlife species diversity, or a more gradual flow of higher-value products than plantations typically provide.

Conversion of uneven-aged to even-aged conditions can be accomplished very quickly—either by clearcutting and planting, or by harvesting to a seed-tree or shelterwood residual basal area (RBA) and encouraging the development of natural regeneration from seed that fall from the residual stand. Conversion from even-aged to uneven-aged conditions takes more time, because trees in the submerchantable size classes are usually not present in sufficient numbers. Development of an uneven-aged diameter distribution may take several cutting cycles, during which time it will be desirable also to maintain adequate volume production.

However, scientific evidence supporting conversion of even-aged to uneven-aged stands, especially in plantations, is limited. Most studies and demonstrations of uneven-aged silviculture in southern pines have focused on recovery from understocked conditions rather than conversion of fully-stocked even-aged structure; this is the case for the Good Farm Forestry Forty and especially the Poor Farm Forestry Forty at the Crossett Experimental Forest in southern Arkansas (Reynolds and others 1984), the Hope Farm Forestry Demonstration at Hope, AR (Farrar and others 1984a), and the Mississippi State Farm Forestry Forties on the Starr Memorial Forest near Starkville, MS (Farrar and others 1989).

The best example of converting even-aged plantations to uneven-aged structure is the Dauerwald, established in the late 19th and early 20th century in southeastern Germany in the state of Anhalt. Stands managed using the Dauerwald were Scotch pine (*Pinus sylvestris* L.) plantations on relatively poor sites with sandy soils, limited vegetative competition, and abundant naturally-occurring regeneration. Those conditions promoted the establishment and development success of regeneration in the smaller size classes, and over time that led to the success of the new method (Troup 1928, Troup 1952).

However, no current replicated research studies to convert even-aged plantations to uneven-aged structure are available for any of the major southern pines in the southern U.S. Therefore, non-replicated demonstrations are an alternative source of data on the mechanics of plantation conversions. One such study is underway in the upper West Gulf Coastal Plain for loblolly (*P. taeda* L.) pine

[1]Research Forest Ecologist and Project Leader, Monticello-Crossett Forestry Sciences Laboratory, Southern Research Station, USDA Forest Service, Monticello, AR.; Forestry Consultant, 880 Old West Point Road, Starkville, MS, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

plantations is the Plantation Conversion Demonstration at the Crossett Experimental Forest.

Our objectives have been to investigate the conversion of even-aged plantations to uneven-aged structure. In the demonstration, two methods of regulating uneven-stands and one method of maintaining even-aged conditions are compared.

METHODS

The demonstration was established in 1980 by the junior author in a 26-year-old loblolly pine plantation located in Compartment 61 of the Crossett Experimental Forest, located in Ashley County approximately 7 miles south of Crossett, AR. Site index for loblolly pine in the study area is 95 feet (base age 50 years). Soils are of the Providence and Bude series, loamy to silt loam in texture, and are poorly drained to moderately well drained.

Three plots, each approximately four acres in size, were located within the plantation. One of three treatments was applied randomly to each plot:

1) Even-aged 80 RBA—-Thinned periodically from below, if operable, to leave 80 square feet per acre of residual basal area.
2) Uneven-aged volume control-guiding diameter limit method (VCGDL)-—Using the volume control-guiding diameter limit method of regulating uneven-aged stands developed by Reynolds (Reynolds and others 1984), stands were operationally treated through periodic cutting until before-cut stand volumes sup ported about 75 square feet per acre of basal area, 2000 cubic feet per acre of total merchantable cubic volume, and 7000 board feet Doyle per acre.
3) Uneven-aged BDq method (BDq)—-The stand was regulated through cutting-cycle harvests using a BDq target stand as the marking guide, where the target stand is set at a residual basal area (the "B" in the BDq acronym) of 60 square feet per acre, a maximum retained d.b.h. (D) of 22", and a q (1-inch classes) of 1.2 (Baker and others 1996).

All three plots were burned by prescription for brush control and hazard reduction during the 1979-80 dormant season prior to study installation. Since then the 80 RBA treatment was burned by prescription during dormant seasons of 1983-84, 1986-87, and 1989-90. All three plots also were treated with herbicides to control unwanted hardwood vegetation; this treatment consisted of basal stem injection of hardwoods 1" d.b.h. and larger using Tordon 101R (picloram plus 2,4-D) in March 1981. In September 1991, a second hardwood control treatment was applied to the uneven-aged plots, consisting of 16 oz. of Arsenal AC (imazapyr) applied using a broadcast sprayer mounted on an articulated rubber-tired skidder.

Data were reported for 12 growing seasons—-summer 1980 through summer 1991. Harvest activity, and inventories to quantify harvest, were conducted during February-March 1981 as the demo was installed, and during the winters of 1983-84 when all plots were harvested, 1986-87 when only the uneven-aged plots were harvested, and 1991-92 when harvest activity occurred on all plots. Inventories of overstory trees were based on 100-percent tallies of all trees 3.6 inches d.b.h. and larger, which were recorded by 1-inch diameter classes and as either pine or hardwood. Overstory plot cruises were conducted, and stands were marked and cut, in each of the dormant seasons of 1980-81, 1983-84, 1986-87, and 1991-92. Marking tallies were also 100-percent tallies of marked trees, recorded by 1-inch d.b.h. classes. After-cut stand conditions were determined by subtracting the marking tally from the cruise tally. For all plots, stand tables were prepared from cruise data using local volume tables.

Regeneration data were tallied as pine or hardwood by 1-inch d.b.h. classes from 0 inches to 3 inches, based on the following classification:

1) 0-inch class—all trees greater than 6 inches in height up to 4.5 feet in height, and if greater than 4.5 feet in height, = 0.5 inches d.b.h.
2) 1-inch class—trees 0.6 inches = d.b.h. = 1.5 inches
3) 2-inch class—trees 1.6 inches = d.b.h. = 2.5 inches
4) 3-inch class—trees 2.6 inches = d.b.h. = 3.5 inches

In the 1980-81 and 1983-84 measurements, regeneration was tallied on 50 0.01-acre fixed-radius plots, by species and diameter class. In the 1986-87 and the 1991-92 measurements, 100 0.001-acre fixed-radius plots (milacres) were sampled for the 0-inch class; for these, milacre stocking percentages were calculated by treatment. In addition, 50 0.01-acre fixed-radius plots were sampled for the 1-inch, 2-inch, and 3-inch classes.

Because overstory data were based on 100-percent tallies, and regeneration data were not replicated, statistical comparisons were not used. Instead, data were presented as summaries for the respective treatments.

RESULTS

Stand Structure over Time

The 80 RBA showed a textbook progression of stand development over time in response to thinning (figure 1). Low thinning removed largely the suppressed,

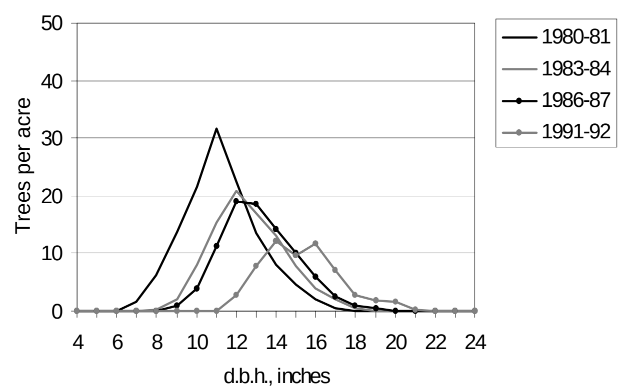


Figure 1—Diameter distribution of the pine component in the even-aged 80 RBA treatment during 1980-81, 1983-84, 1986-87, and 1991-92.

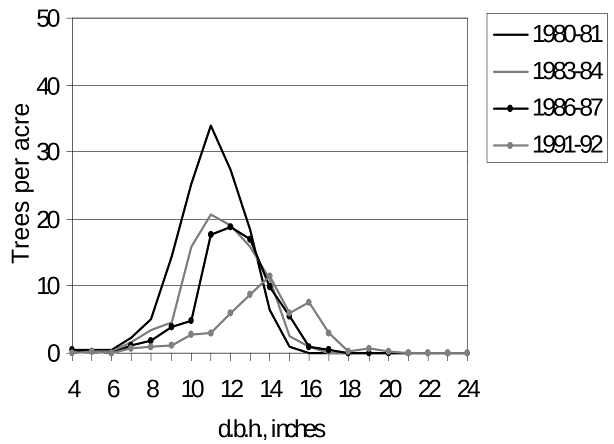


Figure 2—Diameter distribution of the pine component in the uneven-aged volume control-guiding diameter limit treatment during 1980-81, 1983-84, 1986-87, and 1991-92.

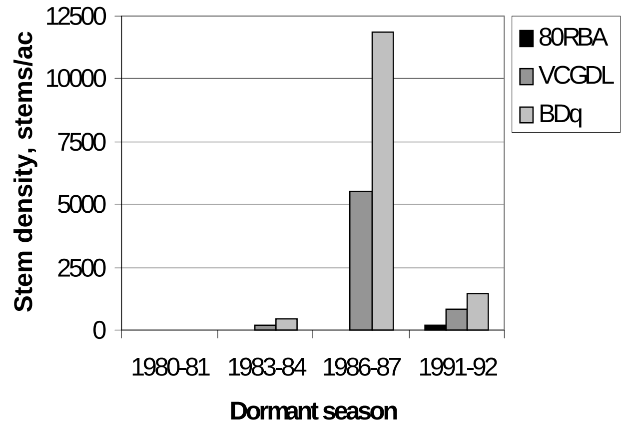


Figure 4—Pine regeneration density by treatment, 0-inch to 3-inch classes inclusive, during 1980-81, 1983-84, 1986-87, and 1991-92.

intermediate, and poorer codominant trees during each harvest. This drove the observed increase both in median diameter and in the size of the smallest trees that remain.

The VCGDL treatment showed a different pattern of residual stands over time (figure 2). Regulation in the VCGDL was done in the sawtimber classes, and the key to implementing the VCGDL method was to "cut the worst trees and leave the best" throughout the range of sawtimber diameters. As a result, there was more whittling away in the larger sawtimber diameter classes than in the low thinning of the 80 RBA treatment and less dramatic shifts in the median diameter. Also, in the VCGDL method, pulpwood-sized trees often were allowed to persist in the stand until they crossed the sawtimber size threshold; a tree's value in board feet is 4 to 10 times greater than its corresponding pulpwood-based cubic-foot value. This resulted in less incentive to remove trees in the subsawtimber classes.

The same principle of 'cut the worst and leave the best' applied in the BDq method (figure 3). But where the VCGDL method encourages the forester to cut the worst and leave the best across all sawtimber diameter classes, the BDq method guides the forester to apply this principle within each merchantable diameter class. This leads to the more obvious pattern of 'taking the top' off the normal curve in the sawtimber component, and shaping the diameter distribution to conform more closely and more rapidly to the reverse J-shaped BDq target distribution.

Periodic Annual Volume Increment

The 12-year periodic annual increment (PAI) for all three treatments exceeds 80 cubic feet per acre for total merchantable cubic volume, and 90 cubic feet per acre for sawtimber cubic volume (table 1). The 80 RBA treatment had the highest values for these variables, exceeding 100 cubic feet per acre annually for the 12-year period. The uneven-aged VCGDL treatment also exceeded 100 cubic feet per acre annually. The BDq treatment had the lowest PAI, falling roughly 20 percent behind the 80 RBA treatment in total merchantable cubic volume, and 13 percent less than the 80 RBA treatment in sawtimber cubic volume.

Twelve-year PAI trends for the sawtimber board foot measures were similar (table 1). All treatments exceeded

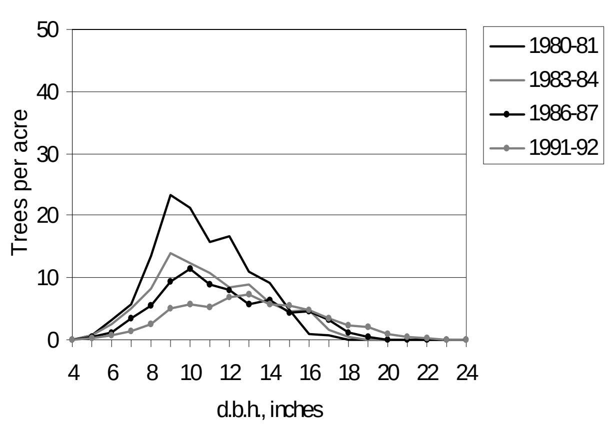


Figure 3—Diameter distribution of the pine component in the uneven-aged BDq treatment during 1980-81, 1983-84, 1986-87, and 1991-92.

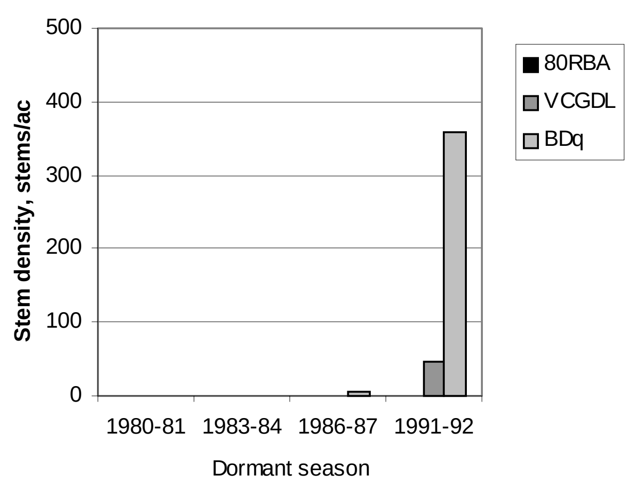


Figure 5—Pine regeneration density by treatment, 1-inch to 3-inch classes inclusive, during 1980-81, 1983-84, 1986-87, and 1991-92.

Table 1—Periodic annual volume increment over 12 growing seasons for the three treatments. TMCV, total merchantable cubic volume; SCV, sawtimber cubic volume, Doyle, sawtimber board-foot volume under the Doyle log rule; Intl. ¼, sawtimber board-foot volume under the International ¼-inch log rule

	TMCV ft^3/ac	SCV ft^3/ac	Doyle fbm/ac	Intl. ¼ fbm/ac
80RBA	106.3	108.0	566.8	716.9
VCGDL	99.7	103.0	493.7	675.3
BDq	84.9	93.6	465.5	633.0

Table 2—Percentage of after-cut basal area in trees 11.6 inches d.b.h. and larger, by inventory year and treatment

	1980-81 *percent*	1983-84 *percent*	1986-87 *percent*	1991-92 *percent*
80RBA	53.8	80.8	88.2	100.0
VCGDL	50.7	63.7	74.4	91.1
BDq	51.4	60.0	66.2	79.0

450 board feet per acre Doyle, and 600 board feet per acre International ¼-inch rule, annually. Again, the 80 RBA treatment was best, the VCGDL treatment was intermediate, and the BDq treatment was poorest. The BDq method had roughly 18 percent less Doyle board foot volume, and 12 percent less International ¼-inch volume, than the 80 RBA treatment. However, the 12-year PAI for all three treatments exceeds the 37-year average annual production of the Good and Poor Farm Forestry Forties for these three volume variables (Guldin and Baker 1988).

Pine Regeneration Density

The cyclical nature of pine regeneration in uneven-aged stands was readily apparent when all regeneration classes were considered (figure 4). By the 1986-87 growing season, pine regeneration density exceeded 5,000 stems per acre in both uneven-aged treatments. But over the next 6 years, those numbers dropped to slightly more than 500 stems per acre of pine regeneration. Pine regeneration did not become established in the even-aged RBA 80 treatment, and none was expected; the 3-year cyclic prescribed burn treatment destroyed most of the pine regeneration that had become established.
Examination of the 1-inch to 3-inch size classes gave a better impression of the successful development of regeneration into larger regeneration classes (figure 5). Provisional standards for acceptable regeneration (Baker and others 1996) suggest that uneven-aged stands require a minimum of 200 stems per acre of desired reproduction. By this standard, only the BDq treatment was effective in promoting development of regeneration into stems larger than 0.5 inch in diameter after 12 years.

Milacre stocking data also show the decline in numbers from 1986-87 to 1991-92 (figure 6). According to Baker and others (1996), the standard for minimum acceptable milacre stocking of desired species is 20 percent. By that standard, both uneven-aged treatments had acceptable milacre stocking in 1986-87, because the VCGDL

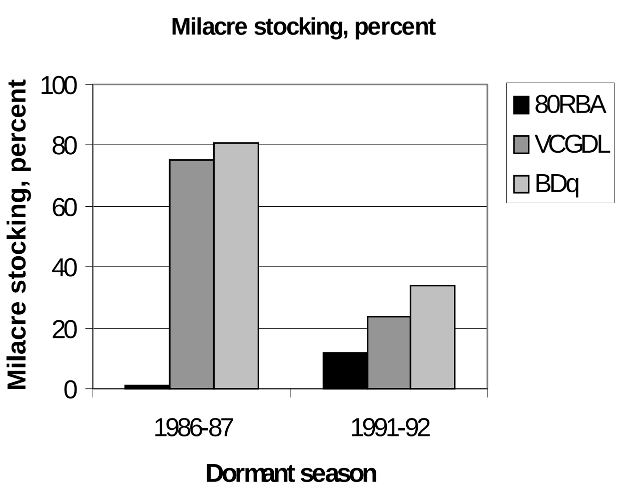


Figure 6—Milacre stocking of pine regeneration by treatment, 0-inch to 3-inch classes inclusive, during 1986-87 and 1991-92.

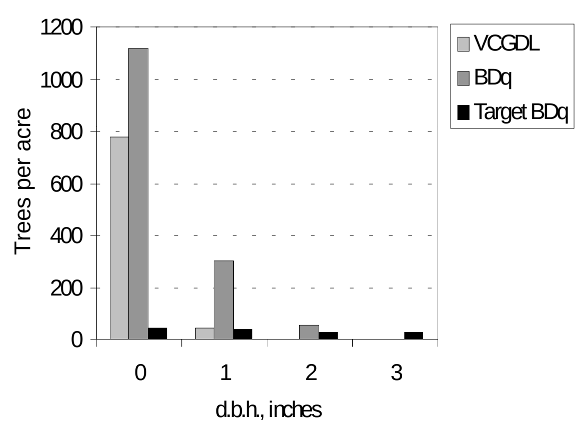


Figure 7—Regeneration density for two uneven-aged treatments compared to that expected based on the target BDq structure.

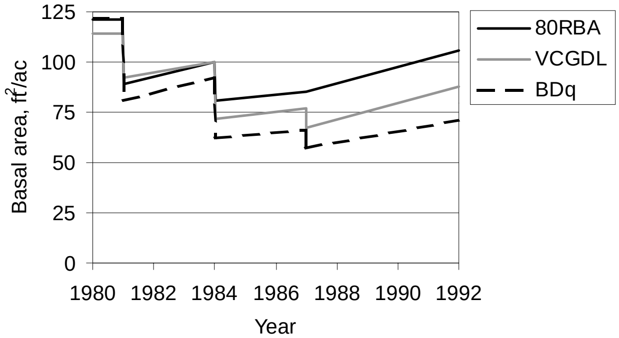


Figure 8—Basal area trends over the 12-year period by treatment.

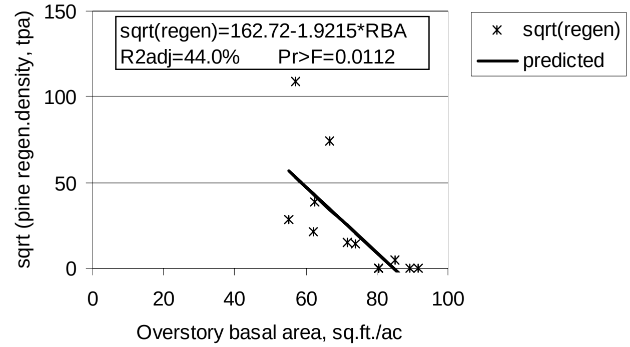


Figure 9—Relationship between before-cut basal area of trees 3.6 inches in d.b.h. and larger versus transformed regeneration density variable.

exceeded 70 percent and the BDq exceeded 80 percent. But by 1991-92, milacre stocking in both treatments had declined. At barely over 20 percent milacre stocking, the VCGDL treatment was marginal; whereas the BDq was acceptable at better than 30 percent milacre stocking.

A final way to judge whether regeneration density is adequate in uneven-aged stands is to compare observed density with that expected under the BDq target structure. The expected density can be calculated from the typical before-cut BDq parameters extended to the 0-inch, 1-inch, 2-inch, and 3-inch d.b.h. classes. Farrar (1996) suggests that the expected density derived in this way should be considered a minimum, and that two to three times that number should be present especially in the smaller size classes, since the rate of mortality of trees in the smaller size classes will be higher. In this demo, the BDq treatment is better than the VCGDL treatment in meeting or exceeding expected numbers by size class (figure 7), although neither treatment has produced adequate regeneration density in the 3-inch class after 12 years.

Basal Area of Different Treatments

High basal area in these treatments also may have adversely affected regeneration development. The BDq treatment was the only one in which after-cut residual basal area fell below 60 square feet per acre, and it was also the only treatment in which basal area remained below 75 square feet per acre from 1984 to 1992 (figure 8). Experience with the Good and Poor Farm Forestry Forties suggests that the best compromise between overstory growth and understory development is to maintain basal area between 60 and 75 square feet per acre (Baker and others 1996, Farrar 1996). Pooling the before-cut inventory data from each treatment with regeneration density data suggested a significant inverse relationship that reinforces these observations (figure 9).

Another factor that may have affected pine regeneration development was the percentage of basal area in sawtimber. Again, experience from the Good and Poor Farm Forestry Forties and elsewhere suggests that from between two-thirds to three-quarters of the total after-cut basal area should be in the sawtimber size classes, which for those stands started with the 12-inch diameter class (Farrar and others 1984b). In these stands, the percentage of basal area in trees 11.6 inches d.b.h. and larger increased over the duration of the study, ultimately exceeding 75 percent in all treatments (table 2).

DISCUSSION

The successful establishment and development of the desired species of regeneration is critical to the success of uneven-aged systems. By this standard, the BDq method was the only successful treatment over the 12-year conversion interval. The VCGDL treatment also exceeded these minimal standards, but only barely; if one tallied only the 1-inch and larger stems, this treatment had a stem density too low to be considered a success.

Conversion from even-aged to uneven-aged conditions is a long process. In 1986-87, both uneven-aged treatments had more than 5,000 stems per acre in the regeneration size classes. However, an additional 6 years of growth led to a prominent reduction in the number of stems in the regeneration size class, especially in the VCGDL treatment with its higher overstory basal area.

After 1987, the original planted trees and one cohort of regeneration had become established. Recruitment of a third age cohort would depend on continued cutting-cycle harvests in the overstory, and these harvests would have to be sufficiently intensive to create growing space for the establishment of new seedlings. But it would be hard to assert that the uneven-aged treatments had, after 12 years, resulted in three distinct age classes.

Suspicion that the process of converting plantations from even-aged to uneven-aged structure is inefficient has not been borne out a 12 year period in this demo. All three treatments had 12-year periodic annual increment exceeding 80 cubic feet per acre in total merchantable and sawtimber cubic volume, 450 board feet per acre Doyle, and 600 board feet per acre International ¼-inch rule.

It might appear anomalous for total merchantable cubic volume PAI to be lower than sawtimber cubic volume PAI. This is attributed to ingrowth into the sawtimber component. Murphy and Shelton (1994) reported similar results. When a tree grows past the 9.6-inch threshold, its sawtimber cubic volume goes instantly from 0 to 6.7 cubic feet, a growth of 6.7 cubic feet. Conversely, its total merchantable cubic volume goes from 10.8 to 14.1 cubic feet, a growth of 3.3 cubic feet. Thus, if ingrowth is high, as it is in this study, sawtimber cubic volume PAI can exceed that of total merchantable cubic volume PAI.

At some point in the life of these plots, volume increment of the original plantation cohort will decline. At another point, the new cohort of trees established during this 12-year period will make contributions to the stand-level PAI. Whether those two points will occur in synchrony to maintain PAI at the levels reported from this 12-year period remain to be seen, but one would suspect that the first point will be reached before the second—and thus that there will be a shortfall in PAI in the next decade or two.

Implications in the distribution of basal area in the sawtimber component are not clear. It has been suggested that the high shade from the crowns of overstory trees alone provide less competition to understory development than an equivalent amount of low shade cast by midstory trees alone (Baker and others 1996). But in this demonstration the opposite appears to be the case, because the treatments with highest percentage of RBA in sawtimber (the 80 RBA and the VCGDL) are those with the least amount of regeneration. The lack of pine regeneration in these two treatments may have resulted from the prescribed burning in the 80 RBA treatment and the generally high levels of residual basal area in both treatments. Some replicated comparisons of regeneration establishment and development beneath pure sawtimber stands versus stands of mixed sawtimber and pulpwood size classes having the same basal area would shed some light on this point.

Finally, this demonstration clearly reveals an important point about converting stands from even-aged to uneven-aged structure using single-tree selection. It is not a rapid process. After 12 years, one of these uneven-aged treatments is headed in the right direction, and the other is marginal. Another decade or two will be needed to judge whether either of these conversion treatments was successful, with new cohorts of regeneration established in sufficient density and stocking, and making acceptable diameter growth into the pulpwood and sawtimber size classes. Additional time will also be needed to determine whether there are unacceptable declines in volume increment over time. Based on this understanding, foresters who plan to undertake the conversion of an even-aged stand to uneven-aged conditions should do so only if they can commit appropriate time to the conversion; time that is more likely to be measured in decades rather than years.

LITERATURE CITED

Baker, James B.; Cain, Michael D.; Guldin, James M. [and others]. 1996. Uneven-aged silviculture for the loblolly and shortleaf pine forest cover types. Gen. Tech. Rep. SO–118. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 65 p.

Farrar, R.M., Jr.; Murphy, P.A.; Colvin, R. 1984a. Hope Farm woodland: 33-year production in an uneven-aged loblolly-shortleaf pine stand. Journal of Forestry. 82(8): 176–179.

Farrar, Robert M., Jr. 1996. Fundamentals of uneven-aged management in southern pine. Misc. Publ. 9. Tallahassee, FL: Tall Timbers Research Station. 68 p.

Farrar, Robert M., Jr.; Murphy, Paul A.; Willett, R. Larry. 1984b. Tables for estimating growth and yield of uneven-aged stands of loblolly-shortleaf pine on average sites in the west gulf area. Bull. 874. Fayetteville, AR: University of Arkansas, Division of Agriculture, Agricultural Experiment Station. 21 p.

Farrar, Robert M., Jr.; Straka, Thomas J.; Burkhardt, Charles E. 1989. A quarter century of selection management on the Mississippi State Farm forestry forties. Tech. Bull. 164. Mississippi State, MS: Mississippi Agricultural and Forestry Experiment Station. 24 p.

Guldin, James M.; Baker, James B. 1988. Yield comparisons from even-aged and uneven-aged loblolly-shortleaf pine stands. Southern Journal of Applied Forestry. 12(2): 107–114.

Reynolds, R.R.; Baker, James B.; Ku, T.T. 1984. Four decades of selection timber management on the Crossett Farm forestry forties. Bull. 972. Fayetteville, AR: University of Arkansas, Division of Agriculture, Agricultural Experiment Station. 43 p.

Troup, R.S. 1928. Silvicultural systems. Oxford, at the Clarendon Press. 216 p.

Troup, R.S. 1952. Silvicultural systems. 2d ed. In: Jones, E.W., ed. London: Oxford University Press. 199 p.

COST EFFECTIVENESS OF NATURAL REGENERATION FOR SUSTAINING PRODUCTION CONTINUITY IN COMMERCIAL PINE PLANTATIONS

T. R. Clason[1]

Abstract—Reforestation is a key to production continuity in commercial pine plantations. Although natural and artificial regeneration methods have been used successfully for pine seedling establishment, it is seedling growth during early stage of plantation development that affects the financial potential of a pine plantation. A study was initiated to determine the effect of regeneration method on seedling growth and development. A seed tree regeneration harvest was compared to a clear cut and plant regeneration harvest. The growth of the natural stand was compared to planted plantations with initial stocking densities of 1,200 and 680 seedlings per acre. In addition, the impact of mechanical and chemical site preparation, and herbaceous weed suppression was evaluated. Merchantable volume at age 15 varied between reforestation methods, seedling stocking densities and vegetation management practices being 540, 1,715, 2,730 and 3,440 feet^3 per acre for natural plantation and three planted plantations, respectively. Age 15 land expectation values for the respective reforestation methods were 135, 170, 785 and 1,053 dollars per acre.

INTRODUCTION

On cut over timber land, productivity of commercial loblolly pine (Pinus taeda L.) plantations depends on seedlings competing successfully for finite levels of soil resources. Reforestation phase of plantation development includes site preparation, regeneration (seedling establishment) and post-establishment weed suppression. Although competitive pressure exerted by an existing plant community hampers early seedling growth, seedling establishment plays a pivotal role in the reforestation process. Regenerated stands should be adequately stocked with well distributed seedlings to optimize soil exploitative potential during the first growing season.

During the first growing season, competition from hardwood brush and herbaceous weeds reduces seedling survival and decreases early diameter and height growth. Thorough site preparation suppresses this initial interference, but as the growing season progresses, encroaching vines, resurgent hardwood brush and unwanted pine seedlings begin to compete vigorously for growing space. Regeneration method, natural or artificial, can have a significant impact on mitigating competitive interference during the seedling stage of plantation development.

Natural regeneration methods have been used successfully to establish seedlings on cut over pine plantations but seedling density is usually excessive. Since, pine diameter growth loss has been detected in both dominant and intermediate crown classes of 3-year-old plantations at seedling densities that exceed 500 trees per acre (TPA) (Sprinz and others 1979), natural regeneration may not be a cost effective seedling establishment method for commercial pine plantations. A study was initiated to determine the cost effectiveness of reforestation methods on growth and development of commercial pine plantations. Growth of a seed tree regenerated plantation will be compared to clear cut and plant regenerated plantations with seedling planting densities of 1,200 and 680 seedlings per acre.

METHODS

Data from two studies were used to compare natural and artificial regenerated pine plantation development and growth. The studies were established at the Hill Farm Research Station on the same site but in different years, 1955 and 1984. Predominant soil types are Mahan fine sandy loam (clayey, kaolinitic, thermic Typic Halpludults) and Wolfpen loamy sand (loamy, siliceous, thermic Arenic Paleudalfs) with a 25 year site index for loblolly pine of 70 feet.

1955 Study

The study was initiated during 1955 in a 25-year-old understock stand of old field loblolly and shortleaf pine (Pinus enchinata Mill) that had a stocking density of 167 TPA and mean DBH of 7.7 inches. The stand was subdivided into sixteen 0.5 acre plots. Twelve plots were randomly selected for a seed tree regeneration harvest that left a residual stand of approximately seven loblolly pines per plot. The four remaining plots were clear cut and prepared to plant pine seedlings. The study treatments were as follows: 1) Seed Tree Harvest and seedbed preparation by disking (STD); 2) Seed Tree Harvest and seedbed preparation by burning (STB); Seed Tree Harvest and no seedbed preparation (STCK); and Clearcut Harvest, mechanical site preparation and plant at 1,200 TPA, 6 ft x 6 ft spacing, (PMS). All logging slash was piled and burned in

[1]Professor, Louisiana State University Agricultural Center, Hill Farm Research Station, Homer, LA 71040

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Age 15 stand growth attributes by reforestation treatment[a]

Reforestation Treatment	Stand Density	DBH	Height	Basal Area
	Trees/Acre	Inches	Feet	$Feet^2$/Acre
Seed Tree (Disced)	1,400	3.5	33	94
Seed Tree (Burned)	1,421	3.5	32	95
Seed Tree (Untreated)	1,407	3.5	33	94
Planted MS(1200 TPA)	618	6.4	42	138
Planted CS(680 TPA)	534	7.0	45	142
Planted CS(680 TPA HWS)	581	7.4	47	175

[a]All trees greater than 1.0 inch dbh

August 1955 followed by seedbed and mechanical site preparation treatments. The STD treatment was broadcast disked to a depth of 4 inches with a standard lift-type tandem disk harrow, the STB treatment was burned in September and the PMS treatment was burned and then disked. Treatments were replicated four times and randomly assigned to the designated harvest plots. After 5 years, all seed trees were removed.

1984 Study

This study was initiated following a clear cut harvest of the 1955 Study. The study area was chemically site prepared with glyphosate applied at 4 lbs. a.i./acre and loblolly pine seedlings were planted at a 8 ft x 8 ft spacing (680 TPA). Three levels of herbaceous weed and two levels of woody brush suppression were combined in a factorial manner to establish six vegetation management regimes of varying intensity. Vegetation management regimes, in descending order of intensity, were: VMR 1) post-planting herbaceous weed suppression for 2 years and woody brush (hardwood and pine) suppression; VMR 2) post-planting herbaceous weed suppression for 1 year and woody brush suppression; VMR 3) no herbaceous weed suppression and woody brush suppression; VMR 4) post-planting herbaceous weed suppression for 2 years and no woody brush suppression; VMR 5) post-planting herbaceous weed suppression for 1 year and no woody brush suppression; and VMR 6) no herbaceous weed suppression and no woody brush suppression. Regimes were replicated six times and assigned in completely random manner to 36 0.3 acre plots. Herbaceous weed suppression treatment was applied with a backpack sprayer using sulfometuron methyl at 1.5 oz. a.i./acre in early spring of the first and second growing seasons. Woody brush suppression treatment was a backpack application of triclopyr amine at 2 lbs. ae/acre in the spring of the fourth growing season to suppress hardwood brush and woody vines and to eliminate every third row of pine seedlings. Pine stocking density in the woody brush suppression treatment plots was reduced to approximately 350 TPA. Growth data from the VMR 5 (PCSHWS) and VMR 6 (PCS) plots were used for the natural and artificial regeneration comparisons.

Growth data for both studies were collected periodically through age 15. Age 15 DBH and height were used to compute age 15 individual pine merchantable volume at a 3-inch inside bark diameter (Van Duesen and others 1981). Actual and published cost and revenue values were used to compute treatment net present value (NPV) and land expectation value (LEV). Growth data within studies were analyzed using SAS general linear model analysis of variance procedures at a 0.05 level of probability. NPV and LEV were used to compare treatment cost effectiveness among studies.

Table 2—Age 15 product volume distribution by reforestation treatment

Reforestation Treatment	Product Volume: Total	Pulpwood	C-N-S	Sawtimber
	$Feet^3$/Acre			
Seed Tree (Disced)	540	540	-----	-----
Seed Tree (Burned)	545	545	-----	-----
Seed Tree (Untreated)	540	540	-----	-----
Planted MS (1200 TPA)	1,715	1,005	710	-----
Planted CS (680 TPA)	2,730	670	2,030	40
Planted CS (680 TPA HWS)	3,440	690	2,690	90

Table 3—DBH size class distribution by reforestation treatment

	Reforestation Treatment					
DBH Class	Seed Tree Disced	Seed Tree Burned	Seed Tree Untreated	Planted MS-1200	Planted CS-680	Planted CS-680-HWS
Inches	-----	-----	-----	Trees/Acre	-----	-----
<1.5	1,147	1,614	653	61	-----	-----
1.6-3.5	731	743	734	1	-----	-----
3.6-5.5	667	666	660	127	-----	-----
5.6-7.5	2	2	2	418	138	90
7.6-9.5	-----	-----	-----	71	382	430
>9.6	-----	-----	-----	-----	14	61
Total	2,547	3,025	2,049	678	534	581

RESULTS

1955 Study Growth

Stand growth differences were detected among reforestation treatments. Although seed tree seedbed preparation did not affect stand productivity, mean seed tree treatment and the PMS treatment growth attributes were significantly different (table 1) . Mean seed tree treatment merchantable tree density exceeded the PMS treatment density by 800 TPA (table 1). However, seed tree basal area and merchantable volume were 47 and 60 percent less than the PMS treatment (tables 1 and 2). Pulpwood and chip-n-saw volume differed between seed tree and PMS treatments with seed tree respective volumes being 465 and 710 feet^3 per acre less than the PMS treatment (table 2). Tree diameter distribution varied between seed tree and PMS treatments. Fifty two percent of the seed tree merchantable stems fell within the 2 to 4 inch DBH class, while 91 percent of the PMS stems were greater than 4 inches (table 3).

1984 Study Growth

Mean tree DBH and height, and stand basal area and merchantable volume differed significantly between treatments (tables 1 and 2). No stand density differences were detected at age 15, but tree survival rates averaged 78 and 85 percent for the PCS and PCSHWS treatments. Although the PCS treatment had 47 fewer trees, mean tree DBH and height were 0.4 inches and 2 feet less than the PCSHWS treatment. Basal area and merchantable volume treatment differences were 33 feet^2 per acre and 710 feet^3 per acre. Treatment volume differential was reflected in product volume distribution, PCSHWS chip-n-saw and sawtimber volumes exceeded the PCS volumes by 690 feet^3 per acre (table 2). Tree DBH distribution varied between treatments with PCSHWS treatment having 95 more trees in the 8 inch and larger DBH class, and 66 percent were 10 inches or larger (table 3).

Financial Comparisons

Since seed tree treatment growth was similar for all seedbed preparation treatments, two seed tree options were compared by pooling growth data, assuming no seedbed preparation cost and leaving or removing seed tree stand for the 15 year comparison period. Therefore, financial comparisons treatments were seed tree with no seed tree removal, seed tree with seed tree removal at age 5, PMS, PCS and PCSHWS. Cost values were determined by actual and published costs (Dubois and others 1999). Revenue values were based on the mean 10-year Louisiana stumpage prices for pulpwood, chip-n-saw and sawtimber between 1991 and 2000. Seed tree treatment costs included the value of the residual seed trees, while planted treatment costs included site preparation, seedling purchase and planting, and herbaceous weed suppression for the PCSHWS treatment. All costs and revenues were discounted at a 8 percent interest rate.

Table 4—Age 15 financial comparisons by reforestation treatment

Reforestation Treatment	Costs	Revenues	NPV	LEV
	-----	-----	Dollars/Acre	-----
Seed Tree (No Harvest)	440	48	(-392)	(-244)
Seed Tree (Harvest)	440	532	92	135
Planted MS(1200 TPA)	194	311	117	170
Planted CS(680 TPA)	164	702	538	785
Planted CS(680 TPA HWS)	200	921	721	1,053

Regeneration method did influence the financial potential of commercial pine plantations. At an 8 percent discount rate, failure to capture seed tree value resulted in a negative NPV and LEV at age 15 (table 4). Although seed tree removal at age 5 produced positive NPV and LEV values, these values were less than any of the planted treatments. Initial planting density and site preparation method impacted the financial potential of the planted treatments, PMS treatment NPV and LEV were $422 and $615 per acre less than PCS treatment (table 4). Although there was no cost differential between mechanical and chemical site preparation, chemical site preparation provided better vegetation suppression during early seedling growth and development. First year herbaceous weed suppression (PCSHWS) improved the financial potential of chemically site prepared planted plantations, increasing NPV and LEV by $187 and $188 per acre.

CONCLUSIONS

Reforestation practices had a significant impact on the financial potential of commercial pine plantations:

1. Seed tree regeneration method was the least cost effective reforestation method. Excessively stocked plantations were susceptible to intraspecific competi tion which reduced growth productivity.
2. In planted plantations, chemical site preparation was more cost-effective than a low intensity mechanical treatment.
3. Wider spaced planting density and first year weed suppression improved reforestation cost effectiveness on the planted plantations

REFERENCES

Dubois, M. R.; K. McNabb; T. J. Straka. 1999. Costs and trends for forestry. Forest Landowmer. 58(2): 3-8.

Sprinz, P.; T. Clason; D. Bower. 1979. Spacing and thinning effects on the growth and development of a loblolly pine plantation, 1-42 p. In T. Clason (Ed.) For. Res. Rep., North Louisiana Hill Farm Exp. Stn., Louisiana Agric. Exp Stn., Homer, LA.

Van Duesen P. C.; A. D. Sullivan; T. C. Matney. 1981. A prediction system for cubic foot volume of loblolly pine applicable through much of its range. Southern Journal of Applied Forestry. 5(4): 186-189.

IMPACT OF SUSTAINABLE FOREST MANAGEMENT ON HARVEST, GROWTH, AND REGENERATION OF SOUTHERN PINE IN THE PIEDMONT AFTER 5 YEARS OF MONITORING

Alexander Clark III and James W. McMinn[1]

Abstract—This paper describes a study established to monitor the implications of ecosystem management choices on natural loblolly and shortleaf pine stands on the Oconee National Forests in the Piedmont of Georgia. The impact of partial harvests, group selection cuts, seed tree cuts and no human disturbance on growth, mortality, species composition, and regeneration were monitored from 1994-95 to 1999. In mature stands with no human disturbance growth average 4.7 percent per acre per year and mortality averaged 2.9 percent per acre per year. In stands with partial cuts growth averaged 6.1 percent and mortality averaged 2.4 percent per acre per year. Sweetgum and red maple were the predominant regeneration seedling species in stands with partial cuts and group selection cuts. Loblolly pine was the predominant seedling species in the seed tree cuts. Seed tree cuts appear to be the most successful forest management method for regenerating loblolly pine stands in the Piedmont.

INTRODUCTION

Piedmont National Forest lands have been managed under the multiple-use concept since the 1960's. Under this concept, objectives were to improve the health, quality and volume of pine stands as well as a variety of other benefits. Older pine stands were clear-cut and planted back to pine or harvested using seed tree cuts to establish pine regeneration. Younger stands were thinned to stimulate pine sawtimber growth.

In the early 1990's an ecosystem approach to managing National Forests was introduced to improve the balance among forest values, conserve biodiversity, and achieve sustainable, healthy conditions while retaining the spiritual, historic and esthetic qualities of the land. Under ecosystem management pine and pine/hardwood stands on National Forests in the Piedmont are being converted from evenaged monocultures to unevenaged or two-aged pine and mixed species stands.

This paper reports on a study established to monitor the implications of ecosystem management practices on loblolly (*Pinus teada* L.) and shortleaf (*P. Echinata* Mill) pine natural stands on the Oconee NF in the Piedmont of Georgia. The impact of partial cuts, group selections cuts, seed tree cuts and no human disturbance on harvest volumes; growth; mortality; and seedling density, species composition, richness, diversity, and evenness are reported.

METHODS

Permanent monitoring plots were established in loblolly/shortleaf pine stands on the Oconee NF in the Piedmont to monitor the reponses of these stands to a range of sustainable ecosystem management practices. The monitoring plots were established in 1994-95 and remeasured in 1999. The management practices monitored included: (1) partial cuts, (2) group selection cuts, (3) seed tree cuts and (4) no active management areas. Included in the partial cuts is single-tree selection, salvage cuts, stand improvement cuts and shelterwood cuts. No active management areas are stands in which no human disturbance occurred between stand inventories in 1994-95 and 1999. The group selection openings were 150 to 200 feet in diameter. Each monitoring plot is a cluster group (CG) consisting of three 1/5-acre circular plots and that were randomly located within each stand selected for monitoring. Cluster groups were established in stands representative of four 20-year age classes (20,40,60, and 80 years) (table 1).

On each 1/5-acre plot all trees m 5.0 inches diameter at breast height (d.b.h.) was located by azimuth and distance from plot center. Species, d.b.h., total height, merchantable height, and tree grade were recorded for each live and

Table 1—Number of Natural Stands Monitored by Management Practice and Age Class

Age Class (Yrs)	No Activity	Partial Cut	Group Selection	Seed Tree
	———	———No.———	———	———
20	2	1		
40	2			
60	4	4	2	1
80	2	2		4

[1]Wood Scientist, and Project Leader (retired), Disturbance and Southern Forests, Southern Research Station, USDA Forest service, 320 Green Street, Athens, GA 30602-2044, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 2—Average Proportion of Basal Area by Species Group for Trees = 5.0 inches DBH Measured in 1994-95 and Remeasured in 1999 by Management Practice

Stand Age	1994-95 Pine	1994-95 Soft Hwds	1994-95 Oaks	1994-95 Other Hard Hwds	1999 Pine	1999 Soft Hwds	1999 Oaks	1999 Other Hard Hwds
Yrs				%				
				No Active Management				
15	87	3	10	0	91	1	8	0
43	88	12	0	0	86	13	1	0
62	75	23	1	1	79	20	1	0
72	80	13	3	4	80	13	2	5
				Partial Cuts				
22	97	2	1	0	96	2	2	0
57	92	6	2	0	94	4	2	0
80	83	8	5	4	84	6	6	4
				Group Selection Cuts				
60	83	16	0	0	4	91	0	5
				Seed Tree cut – No Active cut				
60	91	9	0	0	96	4	0	0
75	83	6	10	1	85	2	12	1
				Seed Tree Cut-Active Cut				
70	83	14	1	2	82	14	0	4

dead tree. Five 1/300-acre micro-plots were located 30 feet from plot center at 72° intervals within each 1/5-acre plot to tally seedlings and saplings. Seedlings (trees up to 1.0-inch d.b.h.) were tallied by species count. Saplings (trees 1.0 to 4.9 inches d.b.h.) were tallied by species, d.b.h. and total height. Softwoods 5.0 to 8.9 inches d.b.h. and hardwoods 5.0 to 10.9 inch d.b.h. were classified as pole timber. Softwoods m 9.0- and hardwoods m 11.0 inches d.b.h. were classified as sawtimber if they contained one or more 16-foot sawlog. Pine sawtimber trees were classified using a tree classification system for mature pine developed by Clark and McAlister (1998) and hardwood sawtimber trees were classified using USDA Forest Service hardwood tree grades (Hanks, 1976).

Stem green weight of wood and bark to a 4 inch dob top was estimated for trees m 5.0 inches dbh based on DBH and total height using equations developed for natural pine in the Piedmont (Clark and others 1990). Stem weight of soft hardwoods, oaks and other hard hardwoods were estimated using equations developed for hardwoods in the southeast (Clark and others 1986). The equations were applied to the dbh and total height measurements recorded for each live tree in 1994-95 and live and dead trees

Table 3—Average Stem Green Biomass/Acre in 1994-95, Biomass in 1999, Harvest, Mortality and Growth for Stands Monitored

Avg Age Yrs	1994-95 Inventory TNS/A	Harvest TNS/A	1999 Inventory TNS/A	Mortality %	Annual Growth[1/] %
			No Active Management		
15	16	0	39	6.3	36.0
43	89	0	109	3.7	5.8
62	69	0	80	3.8	5.1
72	156	0	178	1.3	3.9
			Partial Cuts		
22	67	29	61	2.4	12.2
57	103	24	89	2.7	2.8
80	112	33	85	4.8	3.2
			Group Selection Cuts		
60	108	105	3	0.4	11.0
			Seed Tree Cut – No Activity		
60	31	0	37	0.3	3.6
75	42	0	50	0.6	4.8
			Seed Tree Cut – Active Cut		
70	125	79	49	4.2	4.0

1999. Estimated tree weights were expanded to tons per acre. Trees tallied as dead standing and down dead in 1999 but were live in 1994-95 were classified as mortality. Trees cut and hauled were classified as harvest. Average annual mortality was calculated using the following equation:

Mortality = ((dead / intinv) / yrsgrw) * 100
Where: Mortality = average annual mortality in percent
dead = stem weight of dead trees (tons)
intinv = stem weight of live trees in 1994-95 (tons)
yrsgrw = number of years of growth from 1994-95 to 1999

Average annual growth was estimated using the following equation:

Growth = ((99inv-(intinv-dead-harv) / intinv)/ yrsgrw)* 100
Where:
Growth = average annual growth in percent
Harv = stem weight of trees cut and hauled (tons)

Species diversity and evenness were calculated using Shannon's indices of diversity and evenness based on stem counts (Magurran, 1988).

RESULTS

NO ACTIVE MANAGEMENT

The stands that received no active management contained 75 to 88 percent of their basal area (BA) in pine, 3 to 23 percent in soft hardwoods and the remainder in oaks and other hard hardwoods based on the 1994 inventory (table 2). The remeasurement data shows the BA of these stands changed only slightly from 1994 to 1999. The average total green weight of stems per acre ranged from 16 tons on the 15-year stands to 156 tons on the 72-year stand in 1994-95 (table 3). The stand stem biomass/acre increased on all stands with no active management. Average annual growth among sawtimber stands ranged from 5.8 percent for the 43-year stand to 3.9 percent for the 72-year stand. Average mortality ranged from 3.8 percent for the 62-year stand to only 1.3 percent for the 72-year stand. The average mortality of 15-year stands was 6.3 percent per acre per year. However, these young stands were growing at 36 percent per acre per year because of a 40 percent in-growth from saplings to pole timber from 1994 to 1999 and an average increase in quadratic mean DBH from 6.7 to 7.5 inches (table 4).

Average stems per acre for seedlings decreased in all stands that received no active management from 1994 to 1999 by an average of 58 percent and species richness decreased slightly. This decrease in seedling stems per acre was probably a result of the drought conditions in 1998 and 1999 in the Piedmont. On average species diversity and evenness increased slightly (table 5). The most predominant seedling species in 1994-95 were red maple and dogwood, but in 1999 sweetgum and red maple were the most predominant species in the stands receiving no active management (table 6).

PARTIAL CUTS

Harvesting had little effect on the proportion of BA that was in pine, soft hardwood, oaks or hard hardwood in the partial cut stands (table 2). Before harvest the stands averaged 83 to 97 percent pine and following harvest the stands averaged 84 to 96 percent pine. Number of trees per acre (TPA) before thinning ranged from 390 in the 22-year stand to 103 TPA in the 57-year stand (table 4). After the thinning TPA ranged from 83 in the 22-year stand to 67 in the 57-year stand. The average stem weight per acre before thinning ranged from 67 tons per acre in the 22-year stand to 112 tons per acre in the 80-year stand in 1994-95 (table 3). In the thinning operation 43 percent of the stem biomass in the

Table 4—Average Stand Basal Area/Acre, Trees per Acre (TPA) and Quadratic Mean DBH (QDBH) for Tree = 5.0 Inches DBH Measured in 1994-95 and Remeasured in 1999 by Management Practice

	1994-95			1999		
Stand Age (Yrs)	Basal Area (Ft^2)	TPA (No.)	QDBH Area (In.)	Basal (Ft^2)	TPA (No.)	QDBH (In.)
			No Active Management			
15	40	165	6.7	71	231	7.5
43	77	78	13.5	87	80	14.1
62	68	101	11.1	72	100	11.5
72	126	167	11.8	132	169	12.0
			Partial Cuts			
22	117	390	7.4	83	193	8.9
57	86	103	12.4	67	68	13.4
80	105	147	11.4	73	89	12.3
			Group Selection Cuts			
60	98	115	12.5	5	15	7.8
			Seed Tree Cut – No Activity			
60	28	23	14.9	30	22	15.8
75	33	21	16.9	37	23	17.2
			Seed Tree Cut – Active Cut			
70	108	117	13.0	37	12	23.8

Table 5—Average Stem/Acre, Species Richness, Diversity and Evenness for Seedlings for Stands Measured in 1994-95 and Remeasured in 1999 by Management Practice

Stand Age (Yrs)	1994-95 Stems/Acre (No.)	Richness	Diversity	Evenness	1999 Stems/Acre (No.)	Richness	Diversity	Evenness
				No Active Management				
15	7,840	21	2.2	0.7	3,900	16	2.1	0.8
43	10,040	17	1.7	0.6	3,980	13	1.9	0.8
62	9,340	19	2.1	0.7	6,240	18	2.3	0.8
72	45,860	23	1.4	0.5	16,520	21	1.5	0.5
				Partial Cuts				
22	1,820	15	2.2	0.8	4,360	18	1.9	0.7
57	11,300	20	2.0	0.7	9,451	17	2.0	0.7
80	12,140	21	1.8	0.6	10,480	20	2.0	0.7
				Group Selection Cuts				
60								
				Seed Tree cut – No Active cut				
60	5,740	23	1.9	0.6	8,120	17	1.9	0.7
75	12,340	17	1.8	0.6	9,140	19	1.9	0.7
				Seed Tree Cut-Active Cut				
70	16,540	25	1.9	0.6	8,840	16	2.7	0.7

pole and sawtimber class was harvested in the 22-year stand, 23 percent in the 57-year stand and 29 percent harvested in the 80-year stand. Average mortality ranged from 2.4 percent in the 22-year stand to 4.8 percent in the 80-year stand. Average annual growth ranged from 12.2 percent in the 22-year stand to 2.8 percent in the 57-year stand. Seedling stems per acre increased significantly after the thinning in the 22-year stand but decreased only slightly in the 57 and 80-year stands (table 5). Loblolly pine, red maple and sweetgum were the predominant seedling species in the partial cut stands before harvest in 1994-95. Following harvest in 1999 sweetgum was the predominant seedling species in all partial cut stands.

GROUP SELECTION CUTS

The group selection openings contained 83 percent of their BA in pine and 16 percent in soft hardwoods before the openings were cut (table 2). After the openings were harvested they contained only 4 percent of their BA in pine and 91 percent in soft hardwoods. Harvesting in the group openings removed 105 tons per acre or 97 percent of the pole and sawlog biomass in the openings (table 3). On average the openings contained 98 TPA before harvest and 15 TPA after harvest (table 4). The trees remaining in the openings were growing at an annual average rate of 11 percent and averaged 7.8 inches DBH in 1999. Before harvest the predominant seedling species was dogwood

Table 6—Proportion of Seedling Stems per Acre (%) by Species for Stands Measured in 1994-95 and Remeasured in 1999 by Management Practice

Stand Age (Yrs)	1994-95 Species			1999 Species		
			No Active Management			
15	R. Maple (20)	Sweetgum(15)	Water Oak(11)	Sweetgum(16)	Dogwood(14)	R. Maple(12)
43	Dogwood(27)	Lob. Pine(26)	Sweetgum(13)	Sweetgum(23)	Lob. Pine(18)	Dogwood(16)
62	Dogwood(19)	Lob. Pine(19)	Sweetgum(12)	R. Maple(13)	Lob. Pine(12)	Dogwood(11)
72	R. Maple(6)	Dogwood(17)	Elm(3)	R. Maple(65)	Dogwood(11)	Elm(18)
			Partial Cuts			
22	Sweetgum(37	S. Red Oak(9)	Dogwood(9)	Sweetgum(34)	Lob. Pine(32)	B. Cherry(5)
57	Lob. Pine(35)	Sweetgum(15)	R. Maple(7)	Sweetgum(27)	Lob. Pine(21)	Elm(6)
80	R. Maple(31)	Sweetgum(17)	Lob. Pine(13)	Sweetgum(26)	R. Maple(12)	Lob. Pine(4)
			Group Selection Cuts			
60	Dogwood(24)	Lob. Pine(21)	Sweetgum(20)	Sweetgum(40)	Water Oak(18)	Dogwood(16)
			Seed Tree Cut – No Active Cut			
60	Lob. Pine(45)	Sweetgum(24)	Water Oak(4)	Hawthorn(31)	Lob. Pine(25)	Sweetgum(15)
75	Lob. Pine(50)	R. Maple(11)	Sweetgum(7)	Lob. Pine(36)	R. Maple(7)	Sweetgum(7)
			Seed Tree Cut – Active Cut			
70	Lob. Pine(37)	R. Maple(17)	Dogwood(15)	Lob. Pine(37)	Sweetgum(20)	Elm(9)

followed by loblolly pine. Four years after harvesting the openings sweetgum followed by water oak was the predominant seedling species.

SEED TREE CUT- NO ACTIVE CUT

The proportion of BA per acre in pine increased slightly (2 to 5 percent) and proportion in soft hardwoods decreased slightly (4 to 5 percent) from 1994-95 to 1999 on the stands that were seed tree stands prior to 1994 (table 2). The seed tree stands with on active cut averaged 21 to 23 TPA m 5.0 inches DBH and contained 30 to 37 tons of stem biomass per acre in 1999. The stands were growing at an annual rate of 3.6 to 4.8 percent and had an average mortality of 0.3 to 0.6 percent per year (table 3). Average quadratic mean DBH of the seed trees was 15.8 in the 60-year stand and 17.2 in the 75-year stand (table 4). Stems per acre in seedlings increased from 1994-95 to 1999 on the 60-year stand by 41 percent but decreased on the 75 year stand by 47 percent. In 1994-95 the predominant regeneration seedling species was loblolly pine in the seed tree stands with no active cut. Five years after the initial measurements hawthorn was the predominant seedling species in the 60-year stand but loblolly pine was still the predominant species in the 75-year stands. However, over time the loblolly pine seedlings in the 60-year stand should gain dominance over the hawthorn.

SEED TREE CUT – ACTIVE CUT

Prior to harvest the stand that received the seed tree cut contained 108 TPA m 5.0 inches DBH and 83 percent of its BA per acre was in pine, and 14 percent was in soft hardwoods (table 2). Following the seed tree cut the stand contained only 12 TPA but the proportion of BA per acre in pine and hardwoods was about the same as that prior to harvest. Harvesting removed 79 tons per acre or 63 percent of the stem biomass in the stand (table 3). Following the harvest the remaining seed trees were growing at an average rate of 4.0 percent per year and had an average mortality of 4.2 percent per year. The number of seedling per acre decreased from over 16, 540 per acre prior to the harvest to 8,840 in 1999 or by 47 percent. This decrease was probably a direct result the 1998 and 1999 droughts. In 1994-95 loblolly pine was the predominant seedling species and in 1999, four year after the seed tree cut, loblolly pine was still the predominant species.

SUMMARY

The impact of partial harvests, group selections cuts, seed tree cuts and no human disturbance on growth, mortality, species composition and regeneration were monitored for natural pine stands on the Oconee National Forest in the Piedmont of Georgia from 1994-95 to 1999. The stands monitored contained 75 to 92 percent of their basal area in pine, 3-23 percent in soft hardwoods and 0 to 10 percent in hard hardwoods. The stands monitored ranged in age from 15 to 80 years old. In stands over 20 years old, with no human disturbance, the average annual growth was 4.7 percent and annual mortality averaged 2.9 percent. In stands with partial cuts growth averaged 6.1 percent and mortality averaged 2.4 percent. In stands with no human disturbance sweetgum and red maple were the predominant seedling species. In stands with partial cuts and group selection cuts sweetgum was the most predominant regeneration species. Loblolly pine was the predominant seedling species in the seed tree cuts. Seed tree cuts appear to be the most successful method for regenerating loblolly pine stands in the Piedmont.

ACKNOWLEDGMENTS

This research was sponsored by the Wood Utilization of Ecosystem Management program, a national effort coordinated by the USDA Forest Service Forest Products Research Laboratory, Madison WI.

LITERATURE CITED

Clark III, A. 1994. Heartwood formation in loblolly and longleaf pine for red-cockaded woodpecker nesting cavities. In Jones, E.P. Ed.: Proceedings of 46th annual conference of southeastern association of fish and wildlife agencies. 1992 October 25-28: Corpus Christi, TX 79-87.

Clark III, A.; R.H. McAlister, 1998. A visual tree grading system for estimating southern pine lumber yields in young and mature southern pine. Forest Products Journal 48 (10): 59-67.

Clark III, A.; J. R. Saucier, 1986.Total-tree weight, stem weight, and volume tables for hardwood species in the Southeast. Georgia Forestry Research Paper 60. Macon, GA Georgia Forestry Commission 44 p.

Clark III, A.; J. R. Saucier, 1990. Tables for estimating total-tree, stem weights, and volumes of planted and natural southern pines in the southeast. Georgia Forestry Research Paper 79. Macon, GA Georgia Forestry Commission 13 p.

Hanks, L. F. 1976 Hardwood tree grades for factory lumber. Res. Pap. NE-333. Upper Darby, PA. U.S. Department of Agriculture, Forest Service, Northeast Forest Experiment Station. 81 p.

Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton University press, Princeton, NJ,145-148.

REGENERATION HISTORY OF THREE TABLE MOUNTAIN PINE/PITCH PINE STANDS IN NORTHERN GEORGIA

Patrick Brose, Frank Tainter, and Thomas Waldrop[1]

Abstract—A dendrochronology study was conducted on three ridgetop pine communities in northern Georgia to document the current composition and structure, ascertain when the different species became established, and compare their establishment dates with the occurrence of disturbance or drought. Most oaks and pines in these stands date to the early 1900's and became established after major disturbances by disease, logging, and wildfire. The mountain laurel and mixed mesophytic hardwoods became established after the chestnut blight and institution of wildfire control policies. Drought and precipitation appear to have played little role in the establishment of either pine species. Given the ubiquitous presence of hardwoods and the dominance of mountain laurel in the understory, a regime of no disturbance or a single stand-replacing disturbance may not successfully regenerate either pine species in these stands. Numerous low- to moderate-intensity disturbances may be necessary to reduce the hardwood and laurel components and prepare seedbeds for pitch and Table Mountain pine.

INTRODUCTION

The Southern Appalachian Mountains are renown for their diversity of forest types, one of which is the Table Mountain pine (*Pinus pungens*) / pitch pine (*P. rigida*) community. This rare forest type is found throughout the region on xeric mid-elevational south- and west-facing ridges (Zobell 1969). These species are thought to be fire dependant because of cone serotiny in Table Mountain pine, extreme shade intolerance and exposed seedbed requirements by both species, and a successional shift to hardwoods in the absence of fire (Williams and Johnson 1992). The fire regime for successful regeneration of pitch and Table Mountain pine is thought to be infrequent high-intensity fire, the type of fire that now rarely occurs due to the successful fire control policies of the past 70-80 years (Welch and others 2000).

Recent research has not conclusively shown that high-intensity prescribed fires are absolutely necessary, or even beneficial, in perpetuating Table Mountain pine / pitch pine communities. Waldrop and Brose (1999) analyzed the effects of varying fire intensity levels on successful establishment of Table Mountain pine regeneration. They found the fewest new stems and lowest stocking on sites that had experienced a high-intensity crown fire while the most new stems and highest stocking occurred on sites treated with a moderate-intensity surface fire. However, other low- and moderate-intensity prescribed fires have not resulted in successful establishment of new pine regeneration (Elliot and others 1999, Welch and others 2000).
If fire was an integral part of the perpetuation of Table Mountain pine / pitch pine stands but high-intensity, stand-replacing prescribed fires are not adequately regenerating them, then what was the disturbance regime under which these stands originated and developed? Dendrochronology can be used to help answer that question. The application of this approach to stand dynamics integrates radial growth analysis, species establishment dates, and historic weather records to reconstruct how a stand was initiated and grew into its present state. Dendrochronology is receiving increased usage to reconstruct past disturbance regimes and understand successional dynamics (Mikan and others 1994; Abrams and Orwig 1995) but has only once been used to examine the origin and development of Table Mountain pine communities (Sutherland and others 1995).

In this study, we use dendrochronology to determine when three Table Mountain pine / pitch pine stands originated, how they developed to their present state, and the influence of disturbance and drought on that development.

METHODS

The study was conducted in three stands (Big Ridge, Lower Tallulah, and Upper Tallulah) containing a substantial pitch pine and Table Mountain pine component located in the Chattahoochee National Forest of northern Georgia. The stands were approximately 20-30 ac each, situated on the tops and upper side slopes of two south-facing ridges near Rabun Bald. Elevation for two of the stands was from 3200–3600 ft while the third was at 2800–3000 ft. Soil in all three stands was of the Ashe series which is

[1]Research Silviculturist, USDA Forest Service, Northeastern Research Station, Irvine, PA; Professor; Clemson University, Department of Forest Resources, Clemson, SC; Research Forester, USDA Forest Service, Southern Research Station, Clemson, SC, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Basal area, density, stocking, and relative importance values of tree species found in three Table Mountain pine / pitch pine stands in northern Georgia

Stand	Species[a]	Stems/ac	Stocking	BA/ac	Imp. Value
Upper	QUPR	112	100	55.0	25.75
Tallulah	PIPU	64	77	60.3	20.92
	YSY	82	70	21.2	15.18
	QUCO	39	73	19.2	11.26
	CADE	53	67	0.8	8.87
	ACRU	22	67	5.1	6.87
	OXAR	15	33	8.7	4.90
	QUAL	9	20	11.2	3.95
	AMAR	11	36	2.1	3.58
	SAAL	5	17	1.3	1.65
	ROPS	2	7	1.3	1.01
	CAGL	2	7	0.7	0.53
Big Ridge					
	QUPR	120	100	53.4	21.52
	PIPU	136	100	36.0	19.44
	QUCO	51	86	18.9	10.46
	NYSY	56	71	9.2	8.37
	QUAL	37	57	14.6	7.50
	ACRU	33	64	6.7	6.17
	PIRI	9	43	20.7	6.13
	CADE	40	71	1.1	5.96
	OXAR	13	43	12.0	4.88
	AMAR	20	50	3.5	4.13
	CAGL	9	29	3.5	2.45
	SAAL	4	7	6.9	1.81
	PIST	3	14	2.0	1.17
LowerTallulah					
	PIPU	50	100	37.8	15.96
	QUCO	72	93	30.8	15.61
	NYSY	116	100	11.8	14.92
	QUPR	82	100	21.5	14.86
	ACRU	70	100	7.0	10.83
	PIRI	21	36	30.1	9.44
	CADE	31	50	0.9	4.60
	PIST	15	21	5.2	3.08
	COFL	16	29	2.7	3.00
	CAGL	13	29	1.4	2.53
	SAAL	9	29	2.2	2.42
	ROPS	3	21	3.6	1.60
	OXAR	2	14	3.8	1.22

a - Species codes are the first two letters of the genus and species names, e.g., QUPR = Quercus prinus.

a moderately deep, somewhat excessively well drained soil formed in place by weathering of biotite gneiss and schist (Carson and Green 1981).

In each stand, 12 0.05-ac rectangular plots were selected from previously established plots (Waldrop and Brose 1999) based on presence of Table Mountain pine and location to ensure uniform coverage of the entire stand. In each plot, all trees were identified to species, categorized as dominant, co-dominant, intermediate, or suppressed and measured for dbh. All shrubs were identified to species in two 0.0125-ac rectangular subplots and their heights measured to the nearest 0.5 ft. Percent shrub cover was determined by measuring each shrub canopy twice to the nearest half-foot, first at its widest point then at a right angle to that measurement, averaging the two results, and calculating the area as a proportion of the subplot.

Importance Values (IV) for each species were calculated for each stand from the basal area, density, stocking data.

In each plot, one increment core was extracted from each of three or four dominant/codominant trees and each of three or four intermediate trees. Cores were taken from the uphill side of each tree at a height of 1-ft above the ground in hope of intersecting hidden fire scars. Also in each plot, six to eight cross-sectional discs were cut from shrubs and suppressed trees at the ground line.

Cores were air-dried for several weeks, mounted, and sanded with sandpaper of increasing fineness (120, 220 320, and 400 grit) to expose the annual rings. Cross-sections were similarly dried and sanded. The establishment date for each core and cross-section was determined by absolute aging to the pith under a 40x dissecting microscope. A pith estimator for each species was prepared from cores that intersected the pith and this estimator was then used to age cores that did not intersect the pith.

All pitch and Table Mountain pine cores were visually examined for damage, twisting, or gaps and those exhibiting discongruities were discarded. Annual ring width of the remaining cores was measured to 0.01 mm commencing at the pith and proceeding outward to the bark using a Bannister increment measuring device (J.C. Henson, Laguna Niguel, CA). The raw ring width data were detrended and converted to mean growth indices for each site using ARSTAN (Laboratory of Tree Ring Research, Tucson, AZ).

For ease of reporting the establishment dates, hardwood species of similar silvics were grouped together, i.e., mesic hardwoods included flowering dogwood (*Cornus florida*), red maple (*Acer rubrum*), sourwood (*Oxydendron arborum*), and serviceberry (*Almalanchier alnifolia*) while xeric hardwoods contained American chestnut (*Castanea dentata*), blackgum (*Nyssa sylvatica*), chestnut oak (*Quercus prinus*), pignut hickory (*Carya glabra*), sassafras (*Sassafras albidum*), and scarlet oak (*Q. coccinea*). Mountain laurel (*Kalmia latifolia*), pitch pine, and Table Mountain pine are presented as individual species.

Monthly Palmer Drought indices for Rabun County, GA from 1895 to 2000 were obtained from the National Oceanographic and Atmospheric Administration's website.

RESULTS

All three stands were quite similar in their species composition, structure, density, stocking, total basal area, and relative importance values (table 1). In the overstory, Table Mountain pine and chestnut oak were the dominant conifer and xeric hardwood species, respectively. Pitch pine and scarlet oak were also present in the overstory, although they were not as abundant or widespread as Table Mountain pine and chestnut oak. In the midstory, xeric and mesic hardwoods dominated, especially scarlet oak, blackgum, and red maple while the two pine species were poorly represented. The understory consisted almost exclusively of dense mountain laurel. This shrub layer averaged 8.5 ft tall and was nearly ubiquitous in Big Ridge and Upper Tallulah, cover averaged 77 percent and 89 percent respectively, while in Lower Tallulah, mountain laurel was not as widespread (36 percent coverage). In all three stands, American chestnut stump sprouts were fairly abundant (30-50 stems/acre) and widespread (50-71 percent stocking).

A total of 209 cores and 263 cross-sections was collected from the three stands. Nearly all cores were sound as little difficulty was encountered in extracting them from the trees. Distribution of cores by species group was 47 percent Table Mountain pine, 27 percent xeric hardwood, 17 percent PP, and 7 percent mesic hardwood. Cross-section distribution was 51 percent mountain laurel, 32 percent xeric hardwood, 15 percent mesic hardwood, and 2 percent Table Mountain pine. Thirty of the cross-sections contained exposed or hidden scars. Of those, 19 were from Big Ridge and the scar dated to 1996 (a low-intensity wildfire). The remainder were dated and grouped as 1971 - Lower Tallulah, 4 scars; 1963 - Upper Tallulah, 4 scars; and 1946 - Lower Tallulah, 3 scars. Also at Big Ridge, several large, hollow chestnut oaks and cat-faced pines were found.

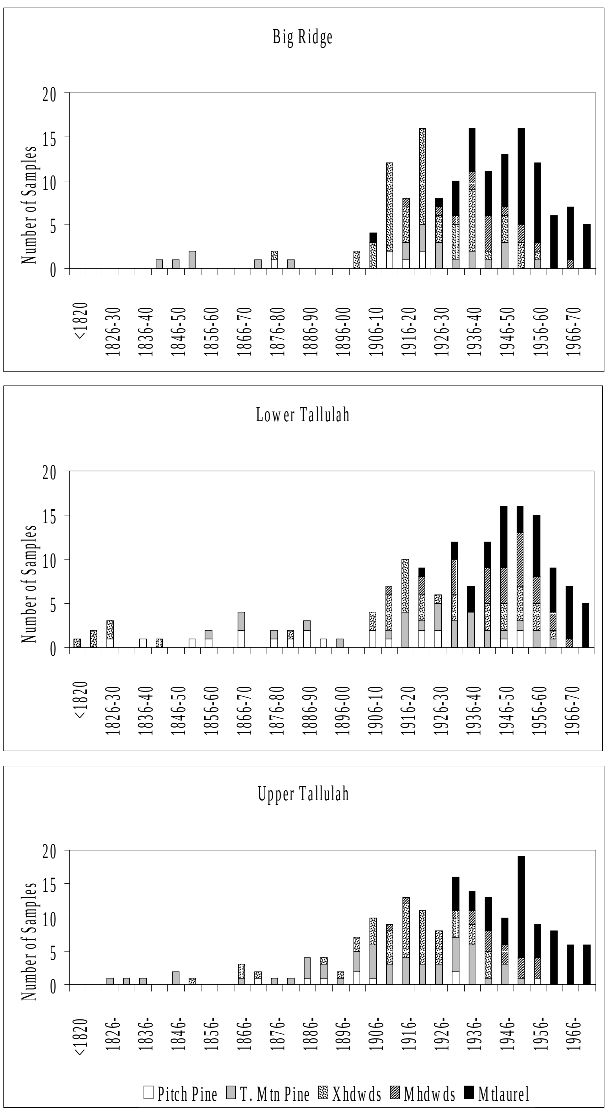


Figure 1—Species establishment dates for three Table Mountain pine stands in northern Georgia.

Species establishment dates and trends were quite similar among the three sites (figure 1). Generally, the oldest trees dated to the early- to mid-1800's and were Table Mountain pine at Big Ridge and Upper Tallulah or chestnut oak and pitch pine at Lower Tallulah. All three species became established in modest episodic amounts during the 19th century. Commencing in the early 1900's and continuing through the 1950's, successful regeneration of Table Mountain pine and the xeric hardwoods (primarily oak) increased relative to the 1800's and were continual in all three stands while pitch pine establishment remained modest and episodic. Pine and xeric hardwood establishment peaked twice in all three stands, first between 1915 and 1925 and again in the early 1930's. Thereafter, establishment of these species declined steadily, eventually ceasing in the late 1950's. Mesic hardwoods, primarily red maple, initially showed up in all three stands beginning in the 1910's and 1920's and were continually established in small to moderate numbers through the 1960's with the 1940's being the decade of most mesic hardwood establishment. Like the oaks, mesic hardwoods have not successfully regenerated in these stands for several decades. Mountain laurel shows up in the stands commencing in the late 1920's. Over the next 50 years it was continually established in large numbers at Big Ridge and Upper Tallulah and to a lesser extent at Lower Tallulah.

The growth index chronologies for both pine species and chestnut and scarlet oak are shown in figure 2. The Table Mountain pine chronologies are fairly robust as the number of trees sampled ranged from 19 to 49. At the two Tallulah stands, growth peaks in the early 1910's, declines until the late 1920's, accelerates until the late 1940's (Upper Tallulah) or late 1950's (Lower Tallulah), then declines until the present. There is no such pattern at the Big Ridge site. In fact, there is no discernable growth pattern at all for Table Mountain pine at Big Ridge.

Pitch pine and oak chronologies are not as robust as Table Mountain pine chronologies because the number of trees sampled is considerably smaller (3 to 21). Among the sites, radial growth patterns for all three species show little similarity to each other nor do they show much similarity to those of Table Mountain pine.

The Palmer Drought Severity Index for 1895 to 2000 is also shown in figure 2. Short-term droughts (1-3 years) were fairly common during the 20th century with especially severe ones occurring in the mid- to late-1920's, throughout the 1930's, mid 1950's, mid 1980's and late 1990's.

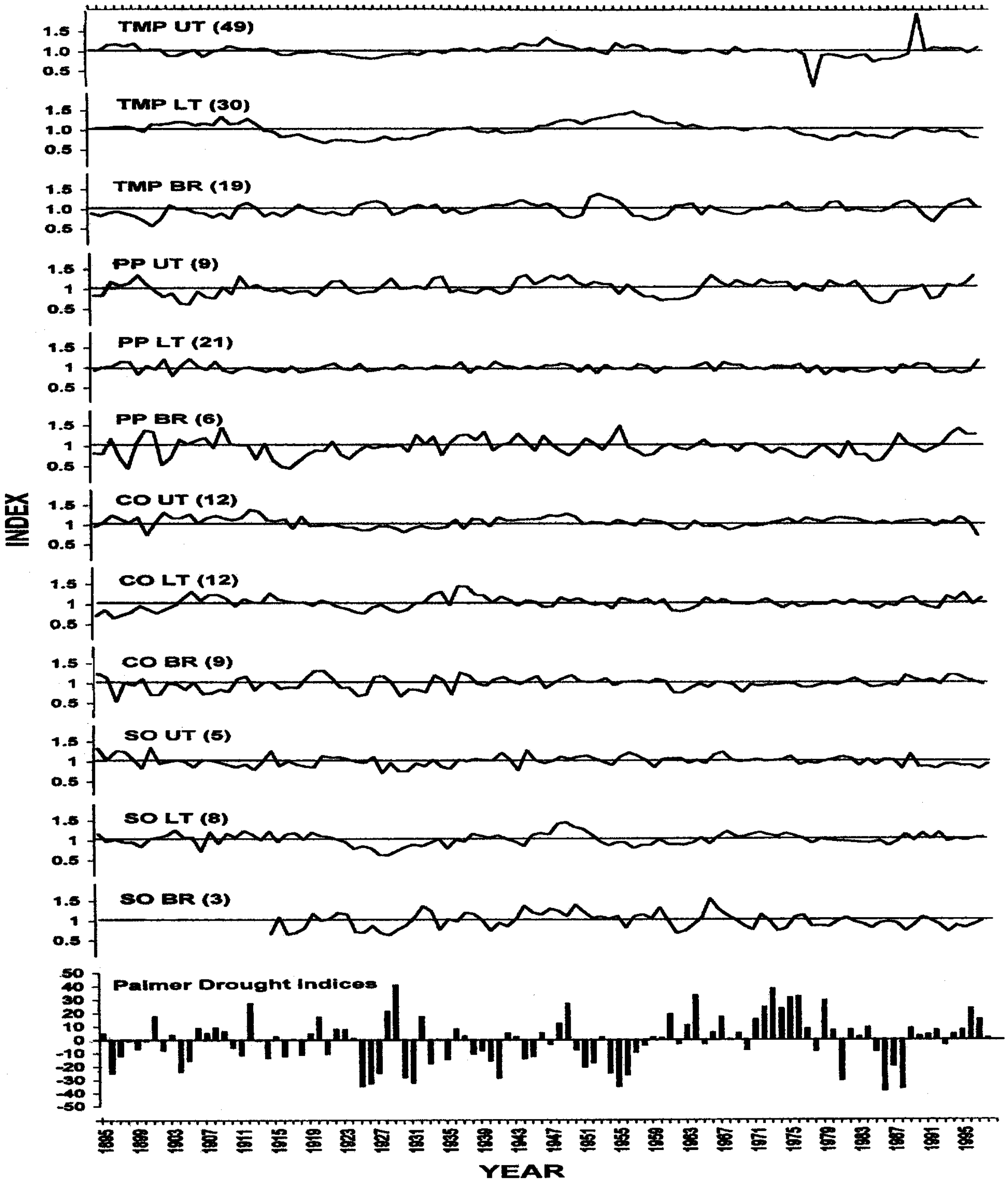


Figure 2—Radial growth chronologies for Table Mountain pine (TMP), pitch pine (PP), chestnut oak (CO), and scarlet oak (SO) and Palmer Drought Indices from 1895 – 2000 for the Big Ridge (BR), Lower Tallulah (LT), and Upper Tallulah (UT) stands in northern Georgia. Numbers in parenthesis indicate sample size.

When compared to species establishment dates in figure 1, drought apparently had little detrimental effect on the regeneration of any of the species.

DISCUSSION

The establishment dates and radial growth data indicate similar, yet different, histories for the three sites. Prior to 1900, these sites supported a mixture of xeric hardwoods (primarily American chestnut and chestnut oak), pitch pine, and Table Mountain pine. Of these, American chestnut probably dominated with the other species forming a moderate minority. The current density and stocking of chestnut stump sprouts (30 to 50 per acre, 60 to 71 percent stocking) indicate the strong position that species formerly held and were probably sufficient to ensure chestnut domination prior to the blight (Paillet and Rutter 1989). Early settlers and travelers often described this forest mixture in this part of Georgia (Plummer 1975).

In that chestnut-oak-pine forest, pitch and Table Mountain pine were able to successfully reproduce but in different patterns. At Upper Tallulah, Table Mountain pine regenerated sporadically before 1865 and continuously after that date. Chestnut oak and pitch pine regenerated episodically during the same time at this location. At Lower Tallulah, all three species regenerated sporadically during the 1800's while only Table Mountain pine successfully regenerated in discrete episodes at Big Ridge.

Apparently, the pre-1900 disturbance regime was conducive to successful regeneration of Table Mountain pine, especially at the Upper Tallulah site. Given the continuous establishment of Table Mountain pine between 1865 and 1900, the lack of rot in the oldest trees, and a near absence of scars in cross-sections, it does not appear that fire was a severe disturbance agent at this site. At Big Ridge and Lower Tallulah, fire may have been more frequent and/or severe, resulting in the episodic regeneration patterns throughout the 1800's.

However, frequent (2 or 3 fires per decade), low-intensity fire may have occurred in all three sites. Such a fire regime would allow some Table Mountain pine regeneration to persist, encouraging establishment of more seedlings, and not causing widespread bole damage to overstory trees. Frequent, low-intensity fires would also encourage regeneration of oak by creating seedbeds and eliminating fire-sensitive competitors (Barnes and Van Lear 1998, Waldrop and Brose 1999).

In the early 1900's, a major disturbance event occurred at all three sites as evidenced by a drop or complete absence of oak and pine regeneration at that time followed by a tremendous establishment surge for 10 to 15 years. Radial growth trends of Table Mountain pine also show an increase at that time, indicating some type of release event. At Big Ridge, this disturbance was undoubtedly a severe fire that few trees survived. Those that did still carry fire scars and/or internal rot. The two Tallulah stands may have experienced some selective logging instead of fire at that time as they probably had more chestnut and are more accessible than Big Ridge. Logging of chestnut became common in the early 1900's when it became evident that the blight was unstoppable (Keever 1953). Also indicating that a severe fire did not occur at that time, trees predating 1900 are more numerous and usually sound, and fire-sensitive, mesic hardwoods begin to be successfully established.

The next major disturbance was in the late 1920's. By that time the American chestnuts that had been killed by the fire or logged would have sprouted, grown into the pole stage, and were probably expressing canopy dominance. The blight killed these developing stands, releasing the codominant oaks and pines, as evidenced by the radial growth increase in Table Mountain pine starting about 1927, and initiating a surge of oak and pine regeneration. Immediately thereafter, establishment of mountain laurel commenced and since then this shrub has come to dominate the understories in all stands, causing all tree regeneration to gradually wane and eventually cease.

Since then, disturbance in these stands appears to have been minimal. Low-intensity surface fires likely occurred in 1946, 1963, and 1971 in the two Tallulah stands but these events impacted only small areas. An outbreak of southern pine bark beetle probably happened in the early 1950's as evidenced by a surge in hardwood and laurel regeneration but not in pine reproduction.

CONCLUSIONS

These Table Mountain pine stands are the product of severe disturbance (fire, logging, and the chestnut blight) followed by decades of little disturbance. The role of occasional low-intensity surface fires in pine regeneration prior to 1900 was probably important but clearly identifying that role was not possible given the analytical limitations of this study. The lack of severe disturbance since the 1930's has allowed mountain laurel to become established and spread. These stands will eventually convert almost entirely to mountain laurel thickets with a few scattered overstory trees if this shrub is not controlled. However, even a severe disturbance may not change that outcome if it is a singular event. To restore these stands to a successfully regenerating oak/pine mixture, numerous low- to moderate-intensity disturbances (herbicide, mechanical, and/or prescribed fires) over a decade or more are needed to remove the laurel and prepare seedbeds.

ACKNOWLEDGMENTS

Partial funding for the research described here was awarded by the Department of Interior/Department of Agriculture, Forest Service Interagency Joint Fire Science Program.

REFERENCES

Abrams, M.D.; Orwig, D.A. 1995. Structure, radial growth dynamics, and recent climatic variations of a 320-year-old Pinus rigida rock outcrop community. Oecologia 101: 353-360.

Barnes, T.A.; Van Lear, D.H. 1998. Fire effects on advanced regeneration in mixed hardwood stands. Southern Journal Appllied Forestry 22(3): 138-142.

Carson, W.S.; Green, T.W. 1981. Soil survey of Rabun and Towns Counties, Georgia. USDA Soil Conservation Service, Athens, GA. 85 p.

Elliott, K.J.; Hendrick, R.L.; Major, A.E.; Vose, J.M.; Swank, W.T. 1999. Vegetation dynamics after a prescribed fire in the Southern Appalachians, Forest Ecology Management. 114: 199-213.

Keever, C. 1953. Present composition of some stands of the former oak-chestnut forest in the southern Blue Ridge Mountains. Ecology 34: 44-55.

Mikan, C.J.; Orwig, D.A.; Abrams, M.D. 1994. Age structure and successional dynamics of a presettlement-origin chestnut oak forest in the Pennsylvania Piedmont. Bullentin Torrey Botany Club. 121: 13-23.

Paillet, F.L.; Rutter, P.A. 1989. Replacement of native oak and hickory tree species by the introduced American chestnut (Castanea dentata) in southwestern Wisconsin. Cannadian Journal Botany 67: 3457-3469.

Plummer, G.L. 1975. 18th century forest of Georgia. Bullentin. Georgia Academy of Science 33:1-19.

Sutherland, E.K.; Grissino-Mayer, H.; Woodhouse, G.A.; Covington, W.W.; Horn, S.; Huckaby, L.; Kerr, R.; Kush, J.; Moore, M.; Plumb, T. 1995. Two centuries of fire in a southwestern Pinus pungens community. In: Inventory and management techniques in the context of catastrophic events: altered states of the forest. Hypertext Proceedings. 1993 June 21-24. University Park, PA. Pennsylvania State University, Center for Statistical Ecology and Environmental Statistics.

Waldrop, T.A.; Brose, P.H. 1999. A comparison of fire intensity levels for stand replacement of Table Mountain pine (Pinus pungens). Forest Ecology Management 113: 155-166.

Welch, N.T.; Waldrop, T.A.; Buckner, E.R. 2000. Response of southern Appalachian Table Mountain pine (Pinus pungens) and pitch pine (P. rigida) stands to prescribed burning. Forest Ecology Management 136: 185-197.

Williams, C.E.; Johnson, W.C. 1992. Factors affecting recruitment of Pinus pungens in the southern Appalachian Mountains. Cannadian Journal Forest Research. 22: 878-887.

Zobel, D.B. 1969. Factors affecting the distribution of Pinus pungens, an Appalachian endemic. Ecological Monographs. 39: 303-333.

PATTERNS OF SEED PRODUCTION IN TABLE MOUNTAIN PINE

Ellen A. Gray, John C. Rennie, Thomas A. Waldrop, and James L. Hanula[1]

Abstract—The lack of regeneration in stands of Table Mountain pine (*Pinus pungens* Lamb.) in the Southern Appalachian Mountains is of concern, particularly to federal land managers. Efforts to regenerate Table Mountain pine (TMP) stands with prescribed burning have been less successful than expected. Several factors that may play a key role in successful regeneration are currently being investigated. The purpose of this study was to determine if TMP seed viability and availability varied with tree age, cone age, and season. Seeds were collected in four seasons from 2- to 5-year-old cones of 5- to 76+-year-old trees. Results indicate that for trees 11 years and older, cones collected in the winter had the highest number of seeds and the higher percentage of viable seeds. Young trees, less than 10 years old, had many seed, but viability was poor. The results of this study can used to identify stands with an adequate number of viable seed.

INTRODUCTION

Researchers and practitioners have assumed that a seed source is always available in serotinous-coned species such as Table Mountain pine (*Pinus pungens*); however, little is known about the specific seed biology of TMP. Table Mountain pine stands of the Southern Appalachians are fire-dependent. In the past, cultural burning practices and lightning-ignited fires provided the necessary disturbance for maintaining these stands. The implementation of fire suppression programs in the early twentieth century has resulted in a subsequent decline of TMP and a shift toward fire-intolerant species. Since the majority of Southern Appalachian TMP is located on public lands, federal agencies have joined together to regenerate TMP with prescribed burning. However, efforts to regenerate stands with prescribed burning have been less successful than expected (Waldrop & Brose 1999).

The objective of this study was to determine if seed viability and availability vary with tree age, cone age, and season in (TMP). Also, differences in the number of cones per tree were evaluated. Information from this study may be used to identify stands adequate numbers of viable seed in addition to suggesting the most appropriate season for burning.

STUDY AREAS

The first criterion in choosing stands for this study was that TMP be the main component of the stand. Second, several tree age classes ranging from 5 to 75+ years needed to be present. Finally, a sufficient number of closed cones ranging in ages from 2 to 5 years needed to be present on the trees of the various age classes.

Several stands in the Nolichucky Ranger District of the Cherokee National Forest (CNF) met the criterion for tree age classes ranging from 11 to 75+ years. Tree age was determined by extracting increment cores at breast height (4.5 ft.) and counting the annual rings.

Additional stands on the Pickens Ranger District of the Sumter National Forest (SNF) and on the Tallulah Ranger District of the Chattahoochee National Forest (ChNF) were needed to provide trees 5 to 10 years of age. In young stands where tree diameter was too small for coring, trees were cut down to determine age.

METHODS

Cone Collection

Cone collection took place in four consecutive seasons, beginning in the fall of 1999 and ending in summer of 2000. One collection was made from each location during each season. Fall months included September, October and November. Subsequent collections for the remaining seasons, winter, spring, and summer included three months for each season.

Sixty-six trees ranging in age from 15 to 148 years (at breast height) were chosen from the three locations in CNF. An aerial lift truck with a 55-foot boom, provided by the U.S.D.A. Forest Service, Southern Research Station, was used for cone collection at the CNF locations.

Forty sample trees ranging in age from 5 to 12 years (at breast height) were chosen from the SNF and ChNF. Access to cones for the younger stands in the SNF and ChNF locations was achieved once trees were cut down.

[1]Graduate Student, Professor Emeritus,Forestry, Wildlife & Fisheries, The University of Tennessee, Knoxville, TN; Research Forester, Southern Research Station, Clemson, SC.; Research Entomologist, Southern Research Station, Athens, GA, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Average number seeds per cone by tree age class, season, and cone age in TMP stands in the CNF, SNF, and ChNF.

Tree age class	Mean[a]
5 - 10 years	46.0a,b
11 – 25 years	51.9a
26 - 50 years	43.5a,b
51 - 75 years	41.5b
76+ years	37.9b
Season Mean[a]	
Fall	45.9a
Winter	49.8a
Spring	39.2b
Summer	37.5b
Cone age Mean[a]	
2 years	38.2b
3 years	46.0a
4 years	47.3a
5 years	47.0a

[a] Means within each group followed by the same letter do not differ at alpha=.05

A total of 264 cones was expected each season from the 66 sample trees. However, infestations of TMP coneworm(*Diorytria yatesi*) reduced the success of finding sound cones. Collections included only 232 cones (88 percent) in the fall, 206 cones (78 percent) in the winter, 185 cones (70 percent) in the spring, and 160 cones (61 percent) in the summer. Each collection produced increasing evidence of coneworm infestation. There was no sign of coneworm damage in the young sample trees on the Sumter and Chattahoochee National Forests.

This study focused on closed cones 2 to 5 years old. To ensure accuracy, cone age for this study was determined by color, position of whorl on branch, and time of year. In addition, no cones were sampled from broken branches. Once removed from the branch, each cone was placed in a separate paper bag. Tree number, cone age, and location were recorded on the bag.

Seed Extraction

Following cone collection for each season, bags were placed one layer thick in a drying oven for a minimum of 12 hours at 60°C to allow cones to open. Following heating, bags were removed and stored at room temperature. Seeds were removed from the cones, by turning the cones upside down and knocking it on a hard surface. Seeds were collected and seed wings removed. Seeds were then counted, placed in small envelopes, and labeled for identification.

Seed Germination

To determine seed viability, a sample of two-thirds of the total number of seeds extracted from each cone was selected for the germination test. For cones containing fewer than three seeds, one seed was selected. The selected seeds from each cone were placed in a covered 100x15 mm plastic Petri dish lined with a 9.0 cm diameter, course filter paper moistened with deionized water. Petri dishes were labeled, sealed with two-inch parafilm to prevent moisture loss, and placed in an incubator and held at a constant temperature of 25°C for 14 days. After 14 days, dishes were removed and opened. Seeds were considered viable if any growth could be seen.

Statistical Analysis

Each cone collected represented one observation. Percent viability was the number of viable seeds divided by the total number of seeds tested times 100. The total number of seeds extracted from each cone and percent viability per cone was then analyzed with ANOVA using the General Linear Methods procedure in SAS (SAS Institute 1997). Variables tested were tree age-classes, seasons, and cone ages, and interactions among these variables. Means were obtained for tree age-classes, seasons, and cone ages, and tested using Duncan's Multiple-Range test. All statistical analyses were conducted using a 95 percent confidence level.

RESULTS

Seed Availability

Significant differences occurred in the number of seeds extracted from a cone by season and also by cone age (table 1). There were no significant interactions of tree age class, cone age, and season. The average number of seeds per cone generally decreased with tree age class. In general, there were two overlapping groups for tree age class: (1) 11-25 years, 5-10 years and 26-50 years; (2) 26-50 years, 51-75 years and 76+ years. The average number of seeds extracted per cone was significantly higher for the winter and fall collections than for the spring and summer collections. Extraction numbers by cone age indicated that seeds were significantly more numerous in 3-, 4-, and 5-year-old cones than in 2-year-old cones.

Percent Viability

Seed viability significantly varied with tree age classes, seasons, and cone ages. The analysis produced no significance in the interactions of tree age class, cone age, and season. Seed viability was highest for the 76+ years tree age class at 38.6 percent and lowest for the 5–10 year tree age class at 8.8 percent. For the 5-10 year tree age class, seed viability was significantly lower than the other classes. Seed viability for winter and spring collections was significantly higher than viability for fall and summer collections. Viability of seeds collected in the summer was significantly lower than that of the other three seasons. Four and 5-year-old cones did not vary significantly, but had significantly higher viability than did 3- and 2-year-old cones. Viability for 3- and 2-year-old cones did not vary. Four and 5-year-old cones did not vary significantly, but had significantly viability than 3- and 2-year-old cones. Viability for 3- and 2-year-old cones did not vary significantly.

Table 2—Average percent viability of seed by tree age class, season, and cone age in TMP stands in the CNF, SNF, and ChNF.

Tree age class	Mean[a]
5- 10 years	8.8b
11 - 25 years	33.3a
26 - 50 years	32.7a
51 - 75 years	32.9a
76+ years	38.6a
Season	Mean[a]
Fall	28.1b
Winter	40.0a
Spring	35.4a
Summer	21.2c
Cone age	Mean[a]
2 years	27.3b
3 years	27.6b
4 years	38.5a
5 years	36.7a

[a] Means within each group followed by the same letter do

DISCUSSION

Lack of regeneration following prescribed fire in the fire-dependent Table Mountain pine stands led to several questions. The questions focused on in this study were, "Can stands with an adequate and viable seed source be identified?" and "Are there differences in seed numbers and viability as a result of tree age, cone age, and/or the season in which the seeds were collected and germinated?"

Seed Numbers and Viability

McIntyre (1929) reported that TMP averaged 49.6 seeds per cone with an average viability of 81 percent. McIntyre (1929) was the only published report with which to compare the results. There was no significant difference in the number of seeds per cone from trees 5 to 76+ years old. However, seeds did decrease in number as tree age increased beginning with the 11-year-old trees. The exception to this trend was the 5- to 10-year-old trees whose seed numbers exceed those trees 26 to 76+ years old. Trees in the 5 to 10 year age class were located farther south in latitude than the 11 to 76+ age class trees, and may have produced differences as a result of soil and climate. McIntyre (1929) found that both drought and heavy precipitation could have a greater influence on cone and seed development than age of tree.

Although trees of all age classes produced an adequate number of seeds, there was a significant drop in percent seed viability and the number of viable seeds per cone in trees 5 to 10 years old. As stated earlier, location may be a factor. This could also be a response to fire intervals in the past. Harmon (1982) and Sutherland and others (1993) showed that prior to acquisition by the U.S. Forest Service, fires occurred approximately every 10 to 12 years in some areas of the Southern Appalachians 1993). Although seed numbers in the 5 to 10 year age class are adequate, low viability in this age class may result in poor regeneration if very young stands are burned too frequently. However, periodic fires are necessary to reduce the establishment of hardwoods which out-compete young seedlings.

Cone Age

The trends for number of seeds per cone and for viability was the same, with 2-year-old cones ranking significantly lower in both categories. Seeds from 3-year-old cones were also significantly lower in percent viability and the number of viable seeds per cone than seeds from the 4- and 5-year-old cones.

This was probably the result of differences in pollenation and other factors in the respective years of cone development. These effects could not be separated because the cones in this study were collected in the same year; that is, 2-year-old cones were initiated in 1998, 3-year-old cones in 1997, and so forth. To separate the effect of cone age from the effect of year would require a multi-year study. This study does suggest, however, that viability does not decrease with time.

Season

Cones collected in winter and fall produced a significantly higher number of seeds than cones from the spring and summer collections. Percent viability was highest in seeds from the winter collection, but not significantly different from spring. The lowest percent viability and the number of viable seeds per cone occurred in seeds in the summer months. This suggests that although cones ripen in autumn of the second season, seed viability may not peak until winter. Mature cones generally turn brown; however, cone color alone may not be sufficient evidence for maturity. To avoid collecting immature seeds, the manual of *Seeds of Woody Plants of North America* (Shopmeyer 1974) suggests checking ripeness in a small sample of cones from individual trees. A mature seed has a firm white or cream-colored endosperm and a yellow to white embryo that nearly fills the endosperm cavity.

The delayed effects of severe drought can cause reduced production of viable seed. In addition, high temperatures can cause premature opening of serotinous cones. It also reduces the production of viable seeds by desynchronizing pollen release and female strobilus receptivity or by inhibiting germination (Zobel 1969).

As seeds age, viability can be maintained for some time. However, they eventually enter a period of rapid decline during which some seeds completely fail to germinate and grow normally. The differences in viability among seeds of the same age can be related to heterogeneity of individual seeds within a seed lot (Kozlowski 1972). Frequent fire is an important technique to perpetuate the existence of genetic diversity within stands and would allow for regular population turnover (Gibson and others 1990).

CONCLUSION

To enhance forest health and reduce fuel concentrations, the United States Department of Agriculture and the United States Department of the Interior have established a national program to increase the use of prescribed fire as a management tool. Without periodic fire, it is unlikely that fire-dependent species such as the Table Mountain pine will achieve optimal regeneration.

To achieve success, several factors are needed including adequate seedbed with available moisture and light, fire intervals that do not negatively affect the microbial activity in the soil, and an adequate and viable seed crop. Tree age is not a factor since stands older than 10 years of age provided an adequate seed source.

Although cones did show some difference in their ability to provide adequate viable seed numbers, there would be no way to discriminate among cones of different ages when burning. Further, although the seeds of Table Mountain pine mature in the fall of the second season, winter provided the highest percentage of viable and number of viable seed.

If management of declining populations is to be effective, the development of a prescribed burning plan should consider tree age and season in which burning is implemented to ensure that an adequate and viable seed source is present.

Further investigation into seed biology should be considered. This study was limited to one year and forced to eliminate trees originally selected due to insect damage and drought conditions. Conducting this research over a longer period of time and over a wider area, would better qualify results.

ACKNOWLEDGMENTS

Financial support was provided by the U.S.D.I., U.S.D.A. Forest Service Joint Fire Sciences Program and the Southern Research Station, SRS-4104 Disturbance and Management of Southern Pine Ecosystems.

REFERENCES

Gibson, J.P.; Hamrick J.L.; Dept. of Genetics. 1990. Genetic diversity and structure in *Pinus pungens* (Table Mountain pine) populations. Canadian Journal of Forestry 21: 635-641.

Harmon, M. 1982. Fire history of the westernmost portion of the Great Smoky Mountains National Park. Bulletin of the Torrey Botanical Club 109: 74-79.

Kozlowski, T.T. 1972. Seed biology: Germination control, metabolism, and pathology (Vol. 2). New York: Academic Press.

McIntyre, A.C. 1929. A cone and seed study of mountain pine (*Pinus pungens* Lambert). American Journal of Botany 16: 402-406.

Schopmeyer, C.S. (*Technical Coordinator*). 1974. Seeds of woody plants in the United States. Agric. Handb. U.S. Department of Agriculture. 450 p.

Sutherland E.K; Grissino-Mayer H.D.; Woodhouse C.A.; Covington W.W.; Horn S., Huckaby L.; Kerr R., Kush J.; Moore M.M.; Plumb T. 1995. Two centuries of fire in a southwestern Virginia Pinus pungens community. In Myers, W.L., ed., Hypertext Proceedings: Inventory and Management in the Context of Catastrophic Events: Altered States of the Forest. University Park, Pennsylvania, Pennsylvania State University.

Waldrop, T.A.; Brose, P.H. 1999. A comparison of fire intensity levels for stand replacement of Table mountain pine (Pinus pungens Lamb.). Forest Ecology and Management 113: 155-156.

Zobel, D.B. 1969. Factors affecting the distribution of *Pinus pungens*, an Appalachian endemic. Ecological Monographs 39: 304-333.

OPTIMAL SEEDBED REQUIREMENTS FOR REGENERATING TABLE MOUNTAIN PINE

Helen H. Mohr, Thomas A. Waldrop, and Victor B. Shelburne[1]

Abstract—High-intensity, stand replacement fires have been recommended to regenerate stands of Table Mountain pine (*Pinus pungens* Lamb.) because its seeds require mineral soil to germinate and seedlings are intolerant of shade. Recent prescribed fires have resulted in poor regeneration, even though crown fires created seedbeds with abundant insolation and thin duff. This study examined regeneration success over a range of duff depth and shading in a greenhouse. Root lengths were compared over a range of duff depths. Table Mountain Pine seeds germinated and seedlings survived on seedbeds with abundant insolation and thin duff. However, stem density was significantly higher under moderate shade and on duff up to 4 in. thick. Seedling roots were able to penetrate duff depths up to 4 in. These findings suggest that prescribed fires of sufficient intensity to eliminate shade and expose mineral soil are unnecessary to regenerate Table Mountain pine.

INTRODUCTION

Fire has existed in the Southern Appalachians for thousands of years, ignited both by humans and by lightning. Humans altered the role of lightning by burning outside of the natural fire season of summer. Pyne and others (1996) described the South as "a biotic putty constantly molded and reshaped but kept malleable by chronic burning." Fire exclusion in the modern Southern Appalachians is a result of policies in place on Federal lands for the last 7 to 8 decades and may explain the decline in many plant communities, including Table Mountain pine (*Pinus pungens* Lamb.) (Waldrop and Brose 1999).

Table Mountain pine grows on steep ridge tops and south-facing slopes of the Appalachian Mountains. It ranges from central Pennsylvania to northeastern Georgia. Typically it is found on xeric sites with rocky soils where only a few hardy species are able to survive the harsh environment. Today oaks encroach on these stands, primarily chestnut oak (*Quercus prinus* L.), and hickories. Serotinous cones and thick bark indicate that Table Mountain pine is a fire-adapted species, which needs fire to regenerate.

Past studies indicate that microhabitat plays an important role in seedling survival. Williams and Johnson (1992) noted that seedling emergence and survival was lower on deep litter. Zobel (1969) indicated that extreme fire aids Table Mountain pine reproduction because it destroys competing vegetation and the litter layer. His research suggested that severe fire is necessary for successful Table Mountain pine regeneration. Severe fires kill canopy trees and undergrowth and expose mineral soil (Zobel 1969). Waldrop and Brose (1999) reported opposing results from a study done in northeastern Georgia. They found that the highest fire intensities produced the lowest density of seedlings.

This study compared different duff depth and shade level combinations to determine the best microhabitat for survival. It also determined duff depth and shade level effects on germination, height growth, root development, soil moisture, and survival.

METHODS

The study was conducted in a greenhouse at Clemson University in Clemson, SC, using a split-plot randomized complete block design. The main plot effect was shade, and the subplot effect was duff depth. Shade levels were 0, 38, 52, and 98 percent and duff depths were 0, 2, and 4 in. Each of the three replications consisted of 4 sets of 24 pots. Each set of 24 pots was randomly assigned a shade level treatment while each pot was randomly assigned a duff depth treatment. This pattern resulted in eight subsamples for each duff depth within each set of 24 pots.

Rectangular PVC boxes were constructed and commercial grade shade cloth was sewn to dimensions to slip over the PVC boxes. These boxes were then placed over each set of 24 pots. Mineral soil and duff (O layer) was gathered from an area that had been burned a few weeks prior on the Andrew Pickens Ranger District of the Sumter National Forest in South Carolina. Soil was placed in 6-in. square pots and either 2 or 4 in. of duff was layered on top of the mineral soil.

Seeds used in the study were gathered from three mature, healthy Table Mountain pines in close proximity on the Tallulah Ranger District in northeast Georgia. Seeds were gathered by cutting the trees down and clipping closed cones from the branches. Cones were then heated at 85 °C for about 20 minutes or until the cones began to open. After the cones cooled and the seeds were shaken out, seed viability was tested in the laboratory. Twenty seeds were placed in five petri dishes lined with moistened paper.

[1]Forester; Research Forester, USDA Forest Service, 239 Lehotsky Hall, Clemson, SC 9634; Associate Professor of Forest Resources, Clemson University, Department of Forest Resources, 260 Lehotsky Hall, Clemson, SC 29634, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Soil moisture by duff depth and shade level

Treatment level	Soil moisture[a] July	Soil moisture[a] August
Duff depth (in.)		
0	2.64a	0.89a
2	3.33ab	2.05b
4	4.10b	2.87c
Shade level		
0	.57a	.30a
Low	1.97b	.62a
Medium	4.06c	2.25b
High	6.83d	4.57c

[a] Means followed by the same letter within a treatment group are not significantly different at the 0.05 level.

Three replications, 18 days each, indicated a 50-percent germination rate.

The greenhouse study began on May 4, 1999, when 25 seeds were placed in each pot. Pots were watered initially and thereafter watering closely followed the rainfall pattern of the first growing season after a prescribed burn in a Table Mountain pine stand in northeastern Georgia (Waldrop and Brose 1999). Rainfall data came from a nearby weather station in Clayton, GA. Watering occurred twice a week during June, once a week in July, and every 10 days in August.

Soil moisture, germination, seedling height, root length, and seedling survival were measured from May 18, 1999, to September 13, 1999. Soil moisture was measured in each pot in July and August. A soil moisture meter was placed in each pot. The moisture was measured on a scale of 0 to 10 where 0 showed no moisture and 10 was fully saturated soil. Seedling germination and survival were measured weekly. New germinants and dead seedlings were counted and recorded for each pot. Seedling height and root length were measured after 3 months and the tallest seedling in each pot was measured. Roots were extracted from the soil, washed, and measured. Total root length and the length of root in mineral soil by duff depth were recorded.

RESULTS AND DISCUSSION

Soil Moisture

Soil moisture was measured to determine the effect of duff depth and shade level as ambient temperature increased and watering became less frequent. In July and August, soil moisture was higher with increased shade and duff (table 1). Soil moisture in July showed a significant difference among all four shade levels. In August there was no significant difference in the 0 and low shade levels, suggesting that medium and high shade levels retain soil moisture by reducing evapotranspiration.

Among duff treatments, in both July and August, soil moisture was highest in 2 and 4 in. of duff. In July the only significant difference in soil moisture was between 0 and 4 in. In August all duff depths were significantly different, suggesting the duff acted as mulch, holding moisture longer. Among all 12 treatment levels (4 shade levels by 3 duff depths) soil moisture was highest under high shade with 4 in. of duff.

Germination

Germination rates ranged from 63 to 71 percent (table 2). There was no statistical difference in percent germination on different duff depths or under different shade levels. Frequent watering during the germination period allowed abundant germination for all treatment combinations.

Seedling Height

Seedling height varied little among duff depths, ranging from 3.5 to 3.8 in. (table 3). Although the range in seedling heights was small, those on 4 in. of duff were significantly taller than those on 0 duff and 2 in. of duff.

Shade level had a more pronounced effect on growth, with seedling heights ranging from 3.0 in. under high shade to 4.1 in. under medium shade. Seedlings grown under low and medium shade were significantly taller than those grown under 0 and high shade. Under high shade, seedlings were probably not getting enough sunlight, although available moisture was plentiful. Zero shade provided plenty of sunlight but lower soil moisture and likely reduced height growth. The optimum combination of shade and duff for height growth was low to medium shade with either 2 or 4 in. of duff. This combination provided enough sunlight without drying the soil.

Table 2—Mean germination by duff depth and shade level

Treatment level	Mean germination[a]
	Percent
Duff depth (in.)	
0	70.7a
2	68.5a
4	63.3a
Shade level	
0	62.6a
Low	67.3a
Medium	69.7a
High	70.6a

[a] Means followed by the same letter within a treatment group are not significantly different at the 0.05 level.

Table 3—Seedling height by duff depth and shade level

Treatment level	Seedling height[a]
	Inches
Duff depth (in.)	
0	3.5a
2	3.6a
4	3.8b
Shade level	
0	3.5a
Low	3.9b
Medium	4.1b
High	3.0c

[a] Means followed by the same letter within a treatment group are not significantly different at the 0.05 level.

Table 4—Root in mineral soil by duff depth and shade level

Treatment level	Root length in soil[a]	Total root length
	---- *Inches* ----	
Duff depth (in.)		
0	4.4a	4.4
2	3.9b	5.9
4	3.8b	7.8
Shade level		
0	6.0a	
Low	5.3b	
Medium	3.5c	
High	1.3d	

[a] Means followed by the same letter within a treatment group are not significantly different at the 0.05 level.

Root Length

Total root length increased from 4.4 to 7.8 in. as duff depth increased (table 4). This pattern suggests that duff depth partially enhanced root growth as roots grew to reach mineral soil. Past research suggested that postfire duff must be thin so that roots could reach mineral soil (Waldrop and Brose 1999, Williams and Johnson 1992). In this study, however, roots penetrated even the thickest duff (4 in.), and there was no difference in root length in mineral soil for 2 or 4 in. of duff (table 4). Root length in mineral soil averaged 3.9 in.

Root length in mineral soil by shade level was significantly different for all four shade levels. As the shade level decreased, root length increased. Seedlings under high shade were probably allocating greater energy to height growth to reach sunlight and less energy to root growth. The longest roots in mineral soil, 6 in., were in 0 shade.

Survival

Survival was significantly greater in duff depths of 2 and 4 in. as compared to 0 duff; however, there was no significant difference between the 2- and 4-in. treatments with 25 percent survival (table 5). Among shade treatments, medium shade had significantly greater survival with more than double any other shade level. All shade levels with either 2 or 4 in. of duff had greater survival than with 0 duff (fig. 1). Again, duff acts as a mulch by retaining soil moisture. Survival was second highest under high shade (15.9 percent). In 0 and low shade, seedlings were getting plenty of sunlight, but the lack of shade caused soil to dry. The best survival was with medium shade and either 2 or 4 in. of duff. Duff depth did not seem to matter as long as some duff was in place.

CONCLUSIONS

Zobel (1969) stated that regeneration persisted in areas where an intense fire had killed canopy trees and almost all the understory. Seedlings persisted especially where erosion had occurred. Therefore, Zobel (1969) suggested that a severe fire is necessary to successfully regenerate Table Mountain pine when there is a well-developed shrub layer. This study may contradict Zobel's findings, suggesting that Table Mountain pine seedlings are able to tolerate more sunlight and duff depth than he reported.

This study showed that medium shade with either 2 or 4 in. of duff was the best treatment combination for successful survival. Medium shade slows moisture loss through evapotranspiration while allowing enough sunlight for successful survival. Seedling roots can penetrate duff up to 4 in., while duff acts as mulch retaining mineral soil moisture for a longer period.

This study indicates that successful regeneration can be achieved with lower intensity and severity fires than once thought. Lower intensity and severity burning produces less risk for loss of control and leaves more duff and litter intact, thereby reducing the chance of erosion occurring on these steep ridge-top slopes. Most importantly, burning at lower fire intensities and severities increases the burning window. High intensity and severity fires are difficult to

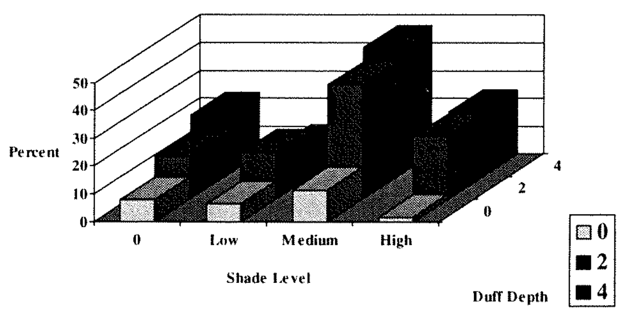


Figure 1—Seedling survival for all combinations of duff depth and shade level.

Table 5—Percent survival by duff depth and shade level

Treatment level	Survival[a]
	Percent
Duff depth (in.)	
0	6.8a
2	24.0b
4	25.5b
Shade level	
0	15.0a
Low	11.3a
Medium	33.0b
High	15.9a

[a] Means followed by the same letter within a treatment group are not significantly different at the 0.05 level.

accomplish because of a limited number of suitable burning days each year.

ACKNOWLEDGMENTS

The authors thank the Clemson University Department of Forest Resources for greenhouse space and the Department of Plant Pathology and Physiology for technical assistance. The U.S. Department of the Interior/U.S. Department of Agriculture, Forest Service Interagency Joint Fire Science Program awarded partial funding for this project.

LITERATURE CITED

Pyne, S.J.; Andrews, P.L.; Laven, R.D. 1996. Introduction to wildland fire. New York: John Wiley. 769 p.

Waldrop, T.A.; Brose, P.H. 1999. A comparison of fire intensity levels for stand replacement of Table Mountain pine (*Pinus pungens* Lamb.). Forest Ecology and Management. 113: 155–166.

Williams, Charles E.; Johnson, W. Carter. 1992. Factors effecting recruitment of *Pinus pungens* in the Southern Appalachian Mountains. Canadian Journal of Forest Research. 22: 878–887.

Zobel, D.B. 1969. Factors affecting the distribution of *Pinus pungens*, an Appalachian endemic. Ecological Monographs. 39: 303–333.

CONE CHARACTERISTICS AND SEED QUALITY 10 YEARS AFTER AN UNEVEN-AGED REGENERATION CUT IN SHORTLEAF PINE STANDS

Kenneth J. Grayson, Robert F. Wittwer, and Michael G. Shelton[1]

Abstract—Cone characteristics and seed quality for 16 released (stand density 14 square meters per hectare) and 16 unreleased (stand density 28 square meters per hectare) shortleaf pine (*Pinus echinata* Mill.) trees were described by d.b.h. class (28, 33, 38, 43 centimeters) and crown position (upper south, upper north, lower south, and lower north). The 38-centimeter d.b.h. class produced significantly heavier cones than other classes. Average cone dry weight for released trees did not differ significantly by crown position, but the lower north crown position produced significantly lighter cones for unreleased trees. Total seeds per cone did not differ significantly between released and unreleased trees, by d.b.h. class, or crown position; the overall average was 46 seeds per cone. Upper crown positions produced a higher percentage of sound seeds per cone (61 percent) than the lower crown positions (50 percent) for both released and unreleased trees. The percentage of sound seeds also differed significantly between released and unreleased trees with the 38- and 43-centimeter d.b.h. classes of released trees producing the highest percentage. Both released and unreleased trees produced significantly more sound seeds per cone in the upper south crown position (31 seeds per cone) compared to the other crown positions (averaging 25 seeds per cone). Seeds from released trees averaged 91 percent germination compared to 85 percent for unreleased trees.

INTRODUCTION

Requirements for adequate quantities of viable shortleaf pine (*Pinus echinata* Mill.) seeds to naturally regenerate forests has increased interest in the cone producing ability of natural stands (Baker 1992). Flower induction is influenced by at least five factors: nutrient relationships, induction hormones, light conditions, soil moisture, and temperature (Barnett and Haugen 1995). A thinning or regeneration cut could positively affect three of the above variables: moisture, light, and nutrients. Yocom (1971) reported that removing all trees within 9.1 meters of shortleaf pine seed trees significantly increased the number of sound seeds per cone and doubled the average cone production per tree. Studies have found that pine seed quality is higher when seedfall is greatest (Stephenson 1963, Shelton and Wittwer 1996). A study of seed quantity and quality in shortleaf pine cones from two 15 hectare natural stands found 36 total seeds per cone with an average of 17.5 and 14.5 sound seeds per cone for single-tree selection and seed-tree stands, respectively (Wittwer and others 1997).

Dickmann and Kozlowski (1971) found seeds per cone for red pine (*Pinus resinosa* Ait.) to depend on the number of productive ovules, degree of pollination, and ovule abortion, and they concluded that the number of productive ovules was not highly dependent on the number of scales. A study of table-mountain pine (*Pinus pungens* Lamb.) found cone length did not affect the number of viable seeds, and there was no relationship between tree age, seed viability, or cone size (McIntyre 1929). A study on young open-grown Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) found the outer extremities of branches on the upper and middle south side of the crown had more cones and greater seed contents except for the west quarter of the crown (Winjum and Johnson 1964).

We conducted this study to determine if cone characteristics and seed quality in shortleaf pine vary by crown position, tree diameter, and release treatment. A better understanding of these relationships will be useful for selecting trees to retain for seed production in natural stands and will provide indicators for forecasting future seed crops.

STUDY AREA

The study area was located in the Ouachita National Forest on the Winona Ranger District, Perry County, AR. Before implementation of uneven-aged management, the stand was irregularly-aged with a uniform canopy dominated by shortleaf pine with mixed hardwoods in the mid to lower canopy. Sixteen uneven-aged management plots (0.20 hectare) were established between December 1988 and March 1989 reducing the overstory pine basal area from 27.6 to 13.8 square meters per hectare (Shelton and Murphy 1997). Plots received one of three residual hardwood basal area treatments (0, 3.4, and 6.9 square meters per hectare). Four plots with complete hardwood control were selected for this study. Each of the 0.20-hectare plots was surrounded by an 18 meter buffer zone receiving the same treatment.

[1]Former Graduate Research Assistant and Professor, Department of Forestry, Oklahoma State University, Stillwater, OK 74078-6013; Research Forester, USDA Forest Service, Southern Research Station, Monticello, AR 71656-3516, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Shortleaf pine site index averaged 17.4 meters at 50 years. Shelton and Murphy (1997) have given a more detailed description of the study area.

METHODS

Tree Selection

Sixteen released trees were selected from the buffer zones of four treated plots, and sixteen unreleased trees were selected from the adjacent unharvested pine-hardwood mixed forest. Sample trees were randomly selected from 5-centimeter d.b.h. classes (28, 33, 38, and 43 centimeters). Sample trees with malformed crowns were excluded from selection. The unreleased stand had about 28 square meters per hectare of total basal area with two-thirds in shortleaf pine and the remainder in hardwoods. Sample trees were measured for height, d.b.h., crown length, crown width, and 5-year radial growth increment at stump height.

Cone Evaluation

Sample trees were felled during the middle of October 1998 when cones were mature but before seed fall. After felling, the crown was measured for total length and was equally divided into upper and lower halves. The crown was further divided into north and south faces creating four crown positions: lower north, lower south, upper north, and upper south. All branches were removed and separated by crown position, providing a complete population of cones for sampling. The four crown positions and four tree d.b.h. classes were considered treatments split between the released and unreleased treatments with four replicates of each treatment. Twenty cones with no visible defects were randomly sampled from each crown position for seed extraction. Very few crown positions failed to produce at least 20 normal cones; all cones were sampled when a shortage occurred. An additional 10 cones per crown position were sampled for dry weight determination. Cone measurements included length, diameter, dry weight, and volume. Cone volume was determined by water displacement. Other cone attributes evaluated were potentially productive scales per cone, total and sound seeds per cone, and percent germination of sound seeds.

Cones were allowed to air dry for 6 weeks and were then tumbled for 25 minutes. Cones were then oven-dried at 35 degrees Centigrade for 48 hours and tumbled for an additional 15 minutes. Most seeds were extracted prior to oven drying, which was a secondary measure to recover any additional seeds. The efficiency of seed extraction was tested by dissecting 80 randomly selected cones after processing; 2.3 seeds per cone were not removed with a coefficient of variation of 63 percent. Potentially productive cone scales, defined as being large enough for two enlarged sound or empty ovules, were counted after all seeds had been removed on 10 of the 20 cones sampled per crown position to determine the potential seed production capacity.

Seed Evaluation

Before further seed evaluation, wings and other inert matter were removed. A series of float tests were used to separate the empty seeds from the sound seeds. To test the efficiency of this process, 20 floating seeds were sampled from each crown position and cut to verify that they were empty. After cutting 2,460 floating seeds, only 1 percent appeared to be sound. Sound seeds were allowed to air dry for 3 days before storing in a refrigerator at 3 degrees Centigrade.

Following Association of Official Seed Analysts (1978) guidelines, a germination test was conducted using a sample of 200 sound seeds per crown position with four replicates of 50 sound seeds each when ample seeds were available. All seeds were used for quantities below 200. Seeds were soaked for 24 hours at 21.1 degrees Centigrade; after draining, seeds were placed in polyethylene bags and stratified for 28 days at 4.4 degrees Centigrade. After stratification, all replicates were placed into 4.5 x 4.5-centimeter dishes with a substrate of three layers of filter paper. Seeds were equally spaced to prevent the spread of fungi from infected seeds. Two milliliters of de-ionized water was added to each dish at the start of the germination test, and 0.20 milliliter was added every 7 days. Fungicide was applied on the fifth day of the germination test to contain mold spread. Light was provided 8 hours per day with a temperature of 30 degrees Centigrade. The remaining 16 hours per day coincided with a temperature of 20 degrees Centigrade.

Germination counts began on the fourth day and continued daily. Seedlings with radicles half the size of the seeds or

Table 1—Results of analyses of variance testing the effects of stand density, tree d.b.h. class, and crown position on cone dry weight, productive scales per cone, percent sound seed, sound seeds per cone, and germination percent

Source of variation	Cone dry weight	Productive scales per cone	Percentage sound seed	Sound seeds per cone	Germination percent
			P-value[a]		
D.b.h. class (D)	0.033	0.292	0.521	0.206	0.113
Stand density (S)	0.021	0.187	0.015	0.054	0.022
DxS	0.122	0.678	0.039	0.323	<0.001
Crown position (P)	0.001	<0.001	<0.001	0.010	0.484
DxP	0.303	0.700	0.463	0.201	0.121
SxP	0.044	0.929	0.934	0.677	0.164
DxPxC	0.293	0.506	0.945	0.964	0.363

[a]*P* level is the probability of obtaining a larger F-statistic

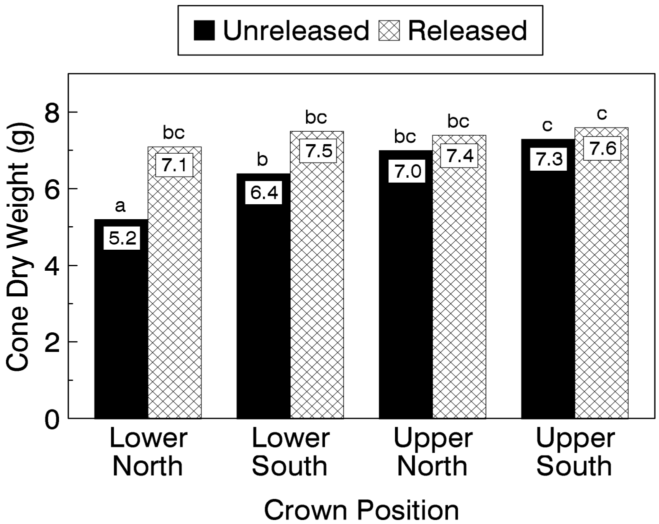


Figure 1—Shortleaf pine cone dry weight for released and unreleased trees by crown position.

longer were evaluated as normal or abnormal according to Association of Official Seed Analysts (1978) standards and removed daily. At the end of testing, seeds that had failed to germinate were cut to determine if they were full or empty. If the percent germination for a replicate deviated by 25 percent or more below the average of all replicates it was omitted from data analysis. Replicates were also omitted when 20 percent or more of the sound seeds were fungi filled. Only 12 replicates out of 450 had to be excluded due to fungi or deviation from the mean percent germination.

Data Analysis

Mean values for cone characteristics were calculated on a per crown position basis. When crown positions lacked enough cones for dry weight determinations, cones already processed for seeds were used; the weight of missing seeds was estimated from the seed weight of the crown position in question. Percent germination was transformed with the arsine square root transformation. The MIXED procedure from the SAS Institute (1997) was used to analyze the data. An analysis of variance for the split-split plot arranged in a randomized complete block design was used to make inferences about cone characteristics by crown positions, d.b.h. class, (split unit treatments) and stand density (main unit treatment). All variables were considered fixed for the mixed model except blocks. Significance was accepted at $\alpha = 0.05$. Multiple mean comparisons were attained by using the LSMEANS statement and DIFF (Fishers Least Significant Difference) and SLICE options (SAS Institute 1997). The SLICE option tests for simple effects; for example, if the interaction of factor A*B is significant, the effect of A for each level of B is tested. Occasionally the relative ranking of all means and their separation may appear contradictory. This may be due to the use of transformed data, multiple standard errors, and missing observations. Multiple standard errors are due to calculations used in the means comparison tests. Means presented in figures are least squares means or estimated means. The only exception is for percent germination, which uses arithmetic means because of the transformation. The arithmetic means and the least squares means will sometimes differ due to an unbalanced design (missing observations).

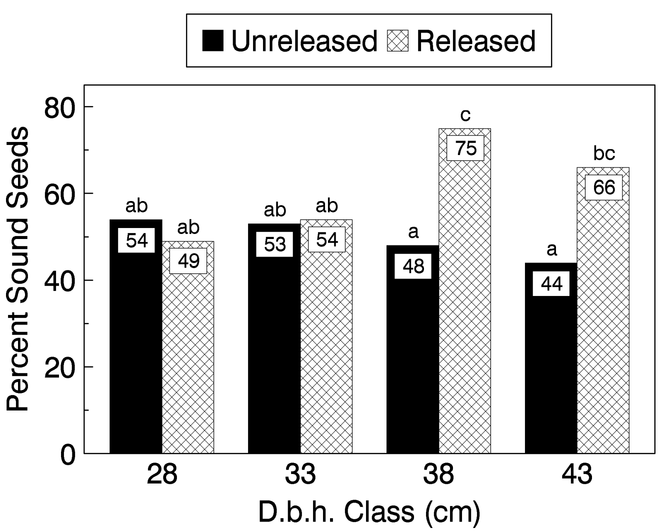


Figure 2—Percentage of sound seed in cones of released and unreleased shortleaf pine by tree d.b.h. class.

RESULTS AND DISCUSSION

Sample Tree Description

Average age (76 vs. 78 years) and height (20.4 vs. 20.1 meters) of released and unreleased shortleaf pine trees were very comparable (Grayson 2000). Crown width (8.2 vs. 7.3 meters) and length (10.1 vs. 9.1 meters) of released trees averaged slightly greater than the unreleased trees. Released trees contained four more branches per tree with a basal diameter of 2.5 centimeters and greater. Released trees grew 0.51 centimeter more than unreleased trees in radial increment at stump height over the last 5 years.

Cone Characteristics

Analyses of variance indicated no significant main effects or interactions for cone length, diameter, and volume, which averaged 4.8 centimeters, 2.2 centimeters, and 11.9 cubic centimeters, respectively. Dry weight of cones differed significantly by d.b.h. class, stand density, and crown position, and a significant interaction occurred between stand density and crown position (table 1). Cone dry weight averaged 7.5 grams per cone for released trees and 6.5 grams for unreleased trees. Trees in the 38-centimeter d.b.h. class produced significantly heavier cones at 8.0 grams compared to all other classes. Cone dry weight on released trees did not differ significantly by crown position, but this was not the case for unreleased trees (figure 1). For unreleased trees, the lower north crown position differed significantly from all other crown positions including the released trees.

The number of potentially productive scales indicates potential seed production with each scale capable of containing two ovules. An analysis of variance indicated a significant effect for crown position (table 1); means were as follows: lower north (53 scales per cone), lower south

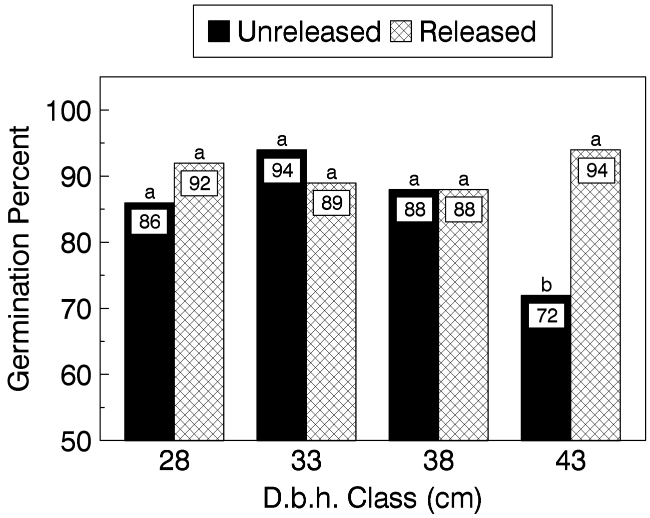


Figure 3—Germination percent of seed from released and unreleased shortleaf pine by tree d.b.h. class.

(55), upper south (56), and upper north (56). The small differences were probably related to differences in cone size by crown position. The total number of seeds per cone was not significantly influenced by tree d.b.h., stand density, or crown position; the overall average was 46 seeds per cone. Despite silvicultural manipulation in the released stand, a gain in total seeds per cone was not apparent.

Seed Characteristics

The percentage of sound seeds was significantly different for stand density, the interaction of stand density and d.b.h. class, and crown position (table 1). Trees in the released stand produced cones with a significantly higher percentage of sound seeds (61 vs. 51 percent of total). There was a trend for the larger trees to produce a higher percentage of sound seeds in the released stand (figure 2). The ranking and means for percent sound seeds by crown position were as follows: lower north (48 percent) = lower south (51) < upper north (59) = upper south (63).

Differences in sound seeds per cone were nearly significant for stand density ($P = 0.054$); averages were 22 seeds per cone for unreleased trees and 31 seeds per cone for released trees. Wakeley (1954) reported that cones average between 25 and 35 sound seeds during a good seed year for shortleaf pine, which is comparable to our results. Lyons (1956) reported that ovule abortion within the cones of red pine may be associated with nutritional factors. If this is the case, released trees in this study could have received a short-term increase in available nutrients, which should have increased overall tree vigor. The reduction in sound seeds for unreleased trees could be due to carbohydrate deficiencies or self-pollination, since both released and unreleased trees produced approximately the same number of total seeds per cone. Reduced air movement in unthinned stands might hamper pollen cloud dispersal and lead to increased self-pollination and embryo abortion.

Crown position was also significant for sound seeds per cone, and means were ranked as follows: lower north (23 sound seeds per cone) = lower south (26) = upper north (26) < upper south (31). According to Perry and Coover (1933), shortleaf pine cones from the top of the crown produced the most viable seeds (24 seeds per cone) followed by the middle crown (20), and finally the crown base (18). The greater sound seed yield in the upper south crown position is probably due to greater carbohydrate production where light levels are higher and growth is more vigorous when compared to other crown positions.

No significant differences in seed weight were found in our study. Dewinged sound seeds per gram ranged from 68 to 132 for released trees and 66 to 147 for unreleased trees, averaging 99 and 95 sound seeds per gram, respectively. Wakeley (1954) reported cleaned and de-winged shortleaf pine seeds average 106 seeds per gram with a range from 80 to 138.

Analysis of variance for germination of sound seeds indicated a significant main effect for stand density and a significant stand density by d.b.h. class interaction (table 1). Seeds from released trees averaged 91 percent germination compared to 85 percent for unreleased trees. Unreleased trees in the largest d.b.h. class (43 Centimeter) exhibited significantly lower seed germination than other size classes for both released and unreleased trees (figure 3). Cone production of trees in this class was low (Grayson 2000), and a positive correlation between cone and seed production and germination percent has been reported (Shelton and Wittwer 1996).

CONCLUSIONS

Cone length, diameter, and volume did not vary significantly by stand density, tree d.b.h., or crown position. Cone dry weight differed significantly between released and unreleased trees. Cone weight also differed significantly by tree d.b.h. class with the 38 centimeter d.b.h. class trees producing heavier cones compared to all other classes. The lower north crown position produced significantly smaller cones by weight compared to all other crown positions. The number of potentially productive scales per cone varied significantly by crown position with the upper north position produced significantly greater numbers. The lower north crown position produced significantly fewer potentially productive scales than all other crown positions. Overall, the differences in cone scale numbers by crown position were small and may not have silvicultural importance.

Percentage of sound seeds per cone differed significantly by stand density, the interaction of density and tree d.b.h., and crown position. The released trees in the 38-centimeter d.b.h. class and larger produced significantly greater percentages of sound seeds when compared to the lower diameter classes and unreleased trees. No significant difference was detected between diameter classes for unreleased trees. For released trees, the general trend was for higher sound seed percentages in the upper crown, with increasing tree diameter. Percentage of sound seed tended to decrease with increasing diameter for unreleased trees. Results for percentage of sound seed suggest that selecting larger diameter released trees, at least 36 centimeters in d.b.h. or greater, will increase seed quality. In addition, released trees produced on average 9 more sound seeds per cone than unreleased trees. The upper south crown position produced significantly more sound seeds per cone than other crown positions by 5 to 8 seeds per cone. Germination of seeds was not significantly affected by crown position or stand density, indicating that germination is consistent within the crowns of released and unreleased shortleaf pine.

The reduction in stand basal area to 14 square meters per hectare, the recommended stocking level in uneven-aged stands, had a pronounced effect on seed production within the stand 10 years later. Enhanced seed production is important to the success of uneven-aged management because regeneration depends on seeds produced by retained trees. Most seeds produced in this stand were on trees with d.b.h. greater than 35 centimeters. Thus, we recommend that maximum diameters used for regulating the stocking and structure of uneven-aged stands be over 35 centimeters. More seeds were produced in the upper canopy. Thus, forecasting systems relying on cone counts or ratings should focus on this portion of the canopy.

REFERENCES

Association of Official Seed Analysts. 1978. Rules for testing seeds. Journal of Seed Technology. 3(3): 1-126.

Baker, J.B. 1992. Natural regeneration of shortleaf pine. In: Brissette, J. C.; Barnett, J. P. comps. Proceedings of the shortleaf pine regeneration workshop; 1991 October 29-31; Little Rock, AR: Gen. Tech. Rep. SO-90. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 102-112.

Barnett, J.P.; Haugen, R.O. 1995. Producing seed crops to naturally regenerate Southern pines. Res. Note SO-286. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 10p.

Dickmann, D.I.; Kozlowski, T.T. 1971. Cone size and seed yield in red pine. American Midland Naturalist. 85: 431-436.

Grayson, K.J. 2000. Distribution and characteristics of shortleaf pine cones after 10 years of uneven-aged silviculture in the Ouachita Mountains. M.S. Thesis. Stillwater, OK: Oklahoma State University. 79 p.

Lyons, L.A. 1956. The seed production capacity and efficiency of red pine cones (*Pinus resinosa* Ait.). Canadian Journal of Botany. 34: 27-36.

McIntyre, A.C. 1929. A cone and seed study of the Mountain pine (*Pinus pungens* Lamb.) American Journal of Botany. 16: 402-406.

Perry, G.S.; Coover, C.A. 1933. Seed source and quality. Journal of Forestry. 31: 19-25.

SAS Institute Inc. 1997. SAS/STAT User's Guide, Release 6.12 Edition. Cary, NC. 1028 p.

Shelton, M.G.; Murphy, P.A. 1997. Understory vegetation 3 years after implementing uneven-aged silviculture in a shortleaf pine-oak stand. Res. Pap. SO-296. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 13p.

Shelton, M.G.; Wittwer, R.F. 1996. Shortleaf pine seed production in natural stands in the Ouachita and Ozark Mountains. Southern Journal of Applied Forestry. 20: 74-80.

Stephenson, G.K. 1963. Ten years of shortleaf pine seed crops in Texas. Journal of Forestry. 61: 270-272.

Wakeley, P.C. 1954. Planting the southern pines. Agric. Monogr. 18. Washington, DC: U.S. Department of Agriculture. 233p.

Winjum, J.K.; Johnson, N.E. 1964. Differences in cone numbers, lengths, and cut-counts in the crowns of young open-grown Douglas-fir. Journal of Forestry. 62: 389-391.

Wittwer, R.F.; Tauer, C.G., Huebschmann, M.M.; Huang, Y. 1997. Estimating seed quantity and quality in shortleaf pine (*Pinus echinata* Mill.) cones from natural stands. New Forests. 14: 45-53.

Yocom, H.A. 1971. Releasing shortleaf pines increases cone and seed production. Res. Note SO-125. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 2p.

DO CONES IN TOPS OF HARVESTED SHORTLEAF PINES CONTRIBUTE TO THE STAND'S SEED SUPPLY?

Michael G. Shelton and Michael D. Cain[1]

Abstract--Because success of natural regeneration strongly depends on a stand's seed supply, we conducted a study to determine the potential contribution of cones in the tops of harvested shortleaf pines (*Pinus echinata* Mill.) if trees were felled after seed maturation but before dispersal was complete. Closed cones, collected in October 1998, were stored in wire cages with periodic removals over the following 9 months to determine the number and viability of extracted seeds. Storage sites were an opening in a seed-tree stand and a closed-canopy pine-hardwood stand. Of the initial average of 30 viable seeds per cone, 93 percent had dispersed in the open site and 83 percent in the closed-canopy stand by the end of February 1999, which is considered the end of the normal dispersal period from cones on standing trees. By May, virtually all viable seeds had dispersed from cones in both sites. Results indicate that cones in tops of trees cut during the 2-month period after seed maturation can make an important contribution to the stand's seed supply, especially in reproduction cutting methods where most of the trees are harvested.

INTRODUCTION

Because of lower establishment costs, natural regeneration is a viable option for shortleaf pine (*Pinus echinata* Mill.) that appeals to many landowners, and about two-thirds of the pine stands in the southeastern United States originated from natural seedfall (USDA Forest Service 1988). Most natural regeneration methods rely on retained trees to produce an adequate seed supply for regeneration. However, trees felled during reproduction cutting may also potentially contribute to the seed supply if felling took place after seed maturation but before complete dispersal. Wakeley (1954) recommended starting in mid-October when collecting shortleaf pine cones for seed extraction. However, Barnett (1976) reported that cones of other southern pines, such as loblolly pine (*P. taeda* L.) and slash pine (*P. elliottii* Engelm.), can yield viable seeds when collected 2 to 3 weeks before recommended dates, suggesting that shortleaf cones may yield viable seeds as early as late September. Shortleaf pine seed dispersal from standing trees is about 50 percent complete by late November and 90 percent complete by the first of January (Wittwer and Shelton 1992). Trees felled in reproduction cutting during the 2-month period from late September to late November have the potential to make a substantial contribution to the stand's seed supply if viable seeds disperse from cones in felled tops. Seeds from tops of cut trees would likely be most important to regeneration success in reproduction methods that remove most of the stand's trees, such as the seed-tree method or small clearcuts.

Although seed dispersal from shortleaf pine trees has been the subject of numerous studies (Stephenson 1963; Wittwer and Shelton 1992; Shelton and Wittwer 1996), we are aware of no earlier investigation of shortleaf pine seed dispersal from cones in tops of felled trees. Objectives of the study were: (1) to determine the potential for cones in the tops of felled shortleaf pine trees to contribute to the stand's supply of viable seeds and (2) to determine the possible fate of seeds dispersed during the growing season when cold, moist stratification that normally promotes germination would not occur.

METHODS

Study Area

The study was located on forest lands of the School of Forest Resources, University of Arkansas at Monticello. The study site is in the West Gulf Coastal Plain at 91 degrees 46 minutes West longitude and 33 degrees 37 minutes North latitude. Elevation is 98 meters with a rolling topography. The soil is a Sacul loam (clayey, mixed, thermic, Aquic Hapludult), a moderately well-drained upland soil with a site index of 21 meters for shortleaf pine at 50 years (Larance and others 1976). The growing season is about 240 days with seasonal extremes being wet winters and dry autumns. Annual precipitation averages 134 centimeters.

Two sites were located for cone storage. The closed-canopy site was located in a mature loblolly/shortleaf pine-hardwood stand. Basal area in trees $\leq$ 9.0 centimeters d.b.h. averaged 25.7 square meters per hectare for pines and 6.4 square meters per hectare for hardwoods; basal area was 2.8 square meters per hectare in trees 9.0 centimeters d.b.h. Light intensity at 1.37 meters in height

[1]Research Foresters, USDA Forest Service, Southern Research Station, Monticello, AR 71656-3516, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

averaged 7 percent of full sunlight at noon during a clear summer day, and the canopy exerted 97 percent ground coverage. The open site was in a 20-meter by 20-meter cleared area within a pine seed-tree stand with approximately 10 sawtimber-sized trees per hectare. This area intermittently received shadows from adjacent trees during the winter months but was mostly in full sunlight during the summer. The open site was 0.4 kilometers from the closed-canopy stand.

Field Procedures

Closed cones were collected from recently harvested shortleaf pines in a mature sawtimber stand in northern Louisiana (October 13, 1998) and a similar stand in southern Arkansas (October 26, 1998). About five tops were sampled in each stand. Immediately after collection, cones were transported to the two study sites and placed in storage frames designed to simulate logging tops but also to provide protection of cones and seeds from predators. The storage frames were 0.5-meter square and made of 1.3-centimeter mesh galvanized hardware cloth. They were held 0.5 meter above the forest floor by legs constructed of 0.6-centimeter diameter steel. This arrangement allowed wind movement around the frame, which we felt was representative of small branches in the top of a felled tree. A top constructed of 0.35-centimeter mesh hardware cloth covered each frame. Cones were attached to the inside surface of the top by intertwining cone-bearing branches through the hardware cloth. Cones were oriented in a downward angle that averaged 45 degrees. Ten cones from each stand were attached to each storage frame's top. The 16 frames at each location provided for up to four removals from field storage with four replicates. The first removal was scheduled for late winter 1999, but subsequent removals were based on observed results. Before seed extraction, cones were always removed from storage when closed; if required, cones were gently sprayed with water the night before removal to cause closure.

To provide field validation, additional cones were sampled in early March 1999 from shortleaf pine tops within a logged area about 0.4 kilometer from the open study site. This mature loblolly/shortleaf pine stand was lightly thinned during late September 1998.

To determine the possible fate of seeds dispersed later than normal, we deposited packets of seeds on the soil surface in the closed-canopy stand and the open site bimonthly beginning in April 1999 and continuing through October 1999. Seeds came from the cones collected in October 1998. After hand dewinging, filled seeds were separated from void seeds and debris by floating in a water bath for 4 hours and collecting the sinking (filled) seeds. Packets were made by uniformly spacing 40 seeds between two pieces of fiberglass window screen that were held in place by two pieces of 1.3-centimeter mesh hardware cloth while in field storage. The packets were intended to protect seeds from predation and to isolate seeds for reduced contamination from pathogens. Each packet measured 14 by 15 centimeters. There were 10 packets for each of the four bimonthly placements; four packets were placed in a prepared seedbed at the open and closed-canopy locations, and two packets were used for germination tests at each time of placement. Packets were stored in a National Weather Service instrument shelter located in the open site from November 1998 until placed on prepared seedbeds. Beginning in April 1999, packets were removed from the shelter bimonthly and placed on an exposed mineral soil surface; then finely ground surface soil from the area was sprinkled on packets until the seeds were lightly covered. Packets were periodically inspected after heavy rains, and soil was added as needed to keep the seeds lightly covered. Each seedbed area contained four packets representing a placement and was completely enclosed within 1.3-centimeter mesh hardware cloth to prevent predation.

To determine the natural pattern of opening and closing of cones, we randomly selected two groups of cones that matured in 1998 and placed them in the storage frames. The percentage openness of each cone was visually assessed just about daily from mid-May through June 1999. To determine cone temperature, a thermometer was inserted into a hole drilled in the base of a test cone and read after stabilization. Readings were also taken of the air temperature in a standard National Weather Service instrument shelter in the open site.

Laboratory Procedures

After removal from field storage, the 20 cones representing each replicate were allowed to air dry in cloth bags for several days until open. Seeds were then extracted by vigorously tumbling cones in a 20-liter plastic bucket. Cones were then lightly heated (33 degrees Centigrade) in a forced-draft oven for 24 hours and a second extraction was made. This process was repeated one additional time. About 90 percent of the seeds were obtained from the first extraction. Seeds were dewinged by hand. After counting, a germination test was conducted by using a subsample of seeds randomly drawn from each replicate. When ample seeds existed, the subsample was either two cups of 50 seeds each or one cup of 75 seeds. When the number of seeds declined below 75 per replicate, all seeds were used in the germination tests.

Test seeds were placed on moist, sterile sand in 10- by 10-centimeter plastic cups and stratified for 30 days at 4 degrees Centigrade. The 30-day germination test was conducted under 10 hours of full-spectrum fluorescent light and 14 hours of dark in accordance with published guidelines (Wakeley 1954). Temperature in the germination room was at 21 degrees Centigrade. A seed was considered to have germinated normally when the seed coat lifted off the sand. A designation of abnormal germination was based on guidelines described by Wakeley (1954). Seeds with fungi were removed immediately to reduce contamination; a cut test was conducted to determine if seeds were full or void (Bonner 1974). At the end of each germination test, a cut test was conducted on all ungerminated seeds; full seeds were classified as being decayed or potentially sound. A seed that germinated normally within the 30 days was considered viable; any full seed that did not germinate normally was considered nonviable.

In February 2000, all packets were removed from field storage, opened, and inspected to count the number of

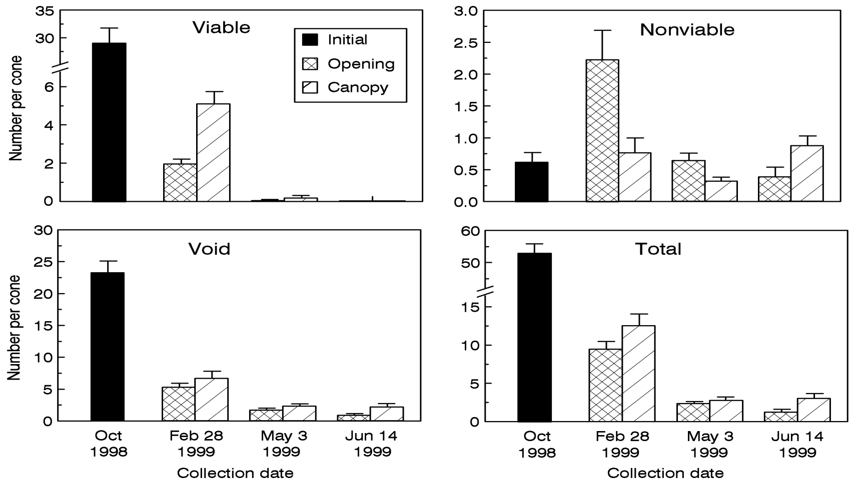


Figure 1—Number and viability of seeds (plus one standard error) observed over a 9-month period during field storage of shortleaf pine cones in an open site and a closed-canopy stand in southeastern Arkansas.

previously germinated seeds based on remnants of a radicle or a split seed coat. A germination test was conducted on all ungerminated seeds as previously described, except that stratification was reduced to 15 days.

Statistical Analysis

The homogeneity of treatment variances was determined by Bartlett's test (Steel and Torrie 1980). When the hypothesis of homogeneity of variance was rejected at $\alpha \leq 0.05$, data were square-root transformed, which provided homogeneity. Analysis of variance was conducted for a completely randomized, split plot in time and space. A split-plot design was used because each storage location and each time interval was singular. All factors were considered fixed. Replicates were considered the germination results of seeds extracted from the samples of 20 cones or from the 40-seed storage packets. Significance was accepted at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Seed Dispersal

The shortleaf pine cones contained an average of 30 viable seeds per cone in October 1998 when they were fully mature (figure 1). This number is typical of years with good seed crops (Wakeley 1954). By late February 1999, viable seeds in the cones had declined by 93 percent in the open site and 83 percent in the closed-canopy stand, and the difference between the two areas was significant (table 1). Seed dispersal from standing shortleaf pines is normally considered complete by the end of February (Wittwer and Shelton 1992). Most of the viable seeds were apparently dispersed because there was no large increase in the number of nonviable seeds over this period.

The viable seeds present in late February (2 seeds per cone in the open site and 5 seeds per cone in the closed-canopy stand) were virtually all dispersed during early spring because few remained in May (<0.2 seed per cone in both the open site and closed-canopy stand). Most of the viable seeds were apparently dispersed because nonviable seeds did not increase over this period. Void seeds showed a similar decline over time as with viable seeds. Our results suggest that void seeds were retained to a greater degree than full seeds (viable and nonviable); void seeds represented 53 percent of the total seeds present in October 1998 but increased to an average of 72 percent in May and June 1999.

Table 1—Analysis of variance for the number of retained seeds in shortleaf pine cones over a 9-month period of field storage in an open site and a closed-canopy stand in southeastern Arkansas

Source of variation[a]	df [b]	Viable seeds MSE[c]	Viable seeds P>F	Nonviable seeds MSE[c]	Nonviable seeds P>F	Void seeds MSE[c]	Void seeds P>F	Total seeds MSE[c]	Total seeds P>F
Location	1	0.72	<0.01	0.18	0.16	0.69	0.03	0.96	0.02
Error I, RxL	6	0.03		0.07		0.08		0.10	
Time	2	7.33	<0.01	0.54	0.01	3.52	0.01	8.56	<0.01
Error II, RxT	6	0.04		0.05		0.08			0.08
LxT	2	0.41	<0.01	0.48	<0.01	0.06	0.41	0.13	0.20
Error III, RxLxT	6	0.02		0.03		0.06			0.06

[a] Location (L), replication (R), and time (T).
[b] Degrees of freedom (df).
[c] Mean square error (MSE) for square root transformed data.

The difference in dispersal pattern between the closed-canopy stand and the open site can be explained by differences in environmental factors, such as wind, temperature, dew, frosts, and humidity. These factors affect the drying of cones and thus the rate and degree of opening and closing. These factors also affect the environmental stresses that seeds are subjected to within cones. In May and June 1999, we observed that cones in the open site took an average of 2 days to open fully following a substantial rain (over 2 centimeters), while those in the closed-canopy stand took 6 days. Cones in the open site closed slightly during nights with heavy dew but fully reopened by midmorning of the following day. Dew did not visibly affect cone closure beneath the closed canopy. During midday, the temperature of cones in the open site averaged 7.5 degrees Centigrade higher than air temperature, while those in the closed-canopy stand were 2.2 degrees Centigrade below the open site's air temperature. The harsher environment of the open site resulted in a more rapid decline in seed viability. Although seeds initially had a 98 percent germination rate, germination of full seeds had declined to 87 percent by February 1999 in the closed-canopy stand and only 47 percent in the open site ($P<0.01$). By May and June 1999, germination of full seeds declined to an average of only 14 percent with no significant difference between the two sites ($P > 0.05$). Cain and Shelton (1997) reported a similar decline in viability for shortleaf pine seeds under field storage. There may be little operational significance of the slower decline in seed viability in the closed-canopy stand, as shade-intolerant shortleaf pine seedlings do not survive for long under such conditions. However, there may be microsites within an opening, such as in the shelter of tops or coarse woody debris, that could provide similar levels of protection.

Field Validation

To determine if the results in our protected storage frames were similar to that found in the field, we conducted additional cone sampling in nearby shortleaf pine stands that had been thinned during late September 1998. The initial base of viable seeds was not known but should have been similar to that of our study because the cones were from the same year. The number of viable seeds in early March 1999 for the thinned stand (9.1 seeds per cone) were very similar to that found in February in our study (5.1 seeds per cone in the closed-canopy stand). The night before the early March collection, a severe rain and wind storm broke the crowns or collapsed about 20 shortleaf pine trees in the stand that was being sampled for cones in logging tops. We collected current-year cones from those trees and confirmed the expected difference in dispersal pattern between standing trees and tops: 0.4 viable seed per cone from the storm-damaged trees compared to 9.1 seeds per cone from the tops ($P = 0.03$). The different seed dispersal pattern from cones of standing trees versus tops of felled trees undoubtedly reflects agitation and drying by the wind, both of which would affect cone openness. Cain and Shelton (1997) reported that a few pine seeds are held so tightly within cones that they may not be dispersed under normal circumstances.

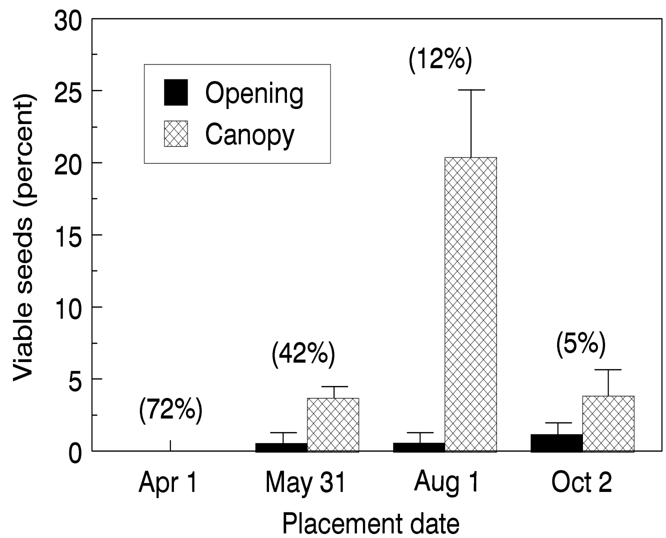


Figure 2—Viable shortleaf pine seeds (plus one standard error) at the end of field testing (February 2000) from packets that had been stored in the open site until placed on mineral soil seedbeds during 1999. The number in parentheses above each bar cluster is the percentage of viable seeds from a subset of packets that were tested for germination at the time of placement.

Seed Fate

Our results indicate that, in a good seed year, 2 to 5 viable seeds per cone could potentially be dispersed from tops after late February if shortleaf pines are felled after seed maturation but before dispersal is completed. Seeds dispersed outside of the normal pattern exhibited from standing trees would not receive the cool, moist stratification that promotes germination. To determine the possible fate of these seeds, seeds extracted from the October 1998 cone collection were placed into packets and were stored in a weather instrument shelter (open site only) awaiting periodic placement in prepared seedbeds. At the time of placement, seed viability declined linearly during the summer, averaging 72 percent for the placement on April 1 and 5 percent on October 2 ($P \leq 0.01$). These results generally agree with the decline in viability that was observed in the stored cones, suggesting that the seeds in the packets accurately represent seeds in cones that potentially could be dispersed.

All the seeds of the April 1999 placement either germinated or died as there was no germination when tested after removal in February 2000 (figure 2). When inspected in February 2000, 76 percent of the seeds from the April 1999 placement had remnants of radicles or had split seed coats. Subsequent placements during the summer and early autumn indicated potential carryover of viable seeds to the next growing season of about 1 percent in the open site and 4 to 20 percent under the closed-canopy stand ($P = 0.01$). The reason for the apparent anomaly in data for the August 1 placement, where germination appeared to increase through time, was not known. The higher potential carryover rates of pine seeds under the closed canopy probably reflected a less harsh environment than in the open site.

CONCLUSIONS

From the standpoint of natural regeneration, the importance of seeds dispersed from cones on felled tops is greater when more of the stand is cut than is retained; thus the potential is greatest in seed-tree stands and in small clearcuts. Our study showed that shortleaf pine cones in tops from an early autumn harvest could potentially disperse up to 93 percent of their viable seeds in time to germinate during the spring. Thus, the potential contribution of tops to a stand's seed supply is large. In addition, these seeds are probably dispersed close to the tops, where regeneration is difficult to obtain because the seedling-to-seed ratio is low (Grano 1949, Shelton and Murphy 1999). The contribution of seed-bearing cones in tops of felled trees is probably more important for regeneration during average seed crops than in good seed crops. Dispersal of seeds from cones in tops of felled trees appears to be enhanced by exposure to sunlight which promotes the drying and opening of cones. However, seed dispersal from cones in tops is prolonged when compared to that of standing trees. Up to 20 percent of the seeds dispersed from cones during the summer could potentially carry-over to the following growing season.

LITERATURE CITED

Barnett, J.P. 1976. Cone and seed maturation of southern pines. Res. Pap. SO–122. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 11 p.

Bonner, F.T. 1974. Seed testing. In: Schopmeyer, C.S., tech. coord. Seeds of woody plants in the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture: 136–152.

Cain, M.D.; Shelton, M.G. 1997. Loblolly and shortleaf pine seed viability through 21 months of field storage: can carry-over occur between seed crops? Canadian Journal of Forest Research. 27: 1901–1904.

Grano, C.X. 1949. Is litter a barrier to the initial establishment of shortleaf and loblolly pine reproduction? Journal of Forestry. 47: 544–548.

Larance, F.C.; Gill, H.V.; Fultz, C.L. 1976. Soil survey of Drew County, Arkansas. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service; XX: Arkansas Agricultural Experiment Station. 86 p. + maps.

Shelton, M.G.; Murphy, P.A. 1999. Disturbance from the initial harvest implementing uneven-aged silviculture in a pine-hardwood stand in southwestern Mississippi. In: Haywood, James D., ed. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16–18; Shreveport, LA. Gen. Tech. Rep. SRS–30; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 397–401.

Shelton, M.G.; Wittwer, R.F. 1996. Seed production in natural shortleaf pine stands in the Ouachita and Ozark Mountains. Southern Journal of Applied Forestry. 20: 74–80.

Steel, R.G.D.; Torrie, J.H. 1980. Principles and procedures of statistics: a biometrical approach. 2^{d} ed. New York: McGraw-Hill. 633 p.

Stephenson, G.K. 1963. Ten years of shortleaf pine seed crops in Texas. Journal of Forestry. 61: 270–272.

U.S. Department of Agriculture, Forest Service. 1988. The South's fourth forest: alternatives for the future. For. Resour. Rep. 24. Washington, DC: U.S. Department of Agriculture, Forest Service. 512 p.

Wakeley, P.C. 1954. Planting the southern pines. Monogr. 18. Washington, DC: U.S. Department of Agriculture. 233 p.

Wittwer, R.F.; Shelton, M.G. 1992. Seed production in natural shortleaf pine stands. In: Brissette, John C.; Barnett, J.P., comps. Proceedings of the shortleaf pine regeneration workshop; 1991 October 29–31; Little Rock, AR. Gen. Tech. Rep. SO–90. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station: 113–123.

FIELD PERFORMANCE OF HIGH-QUALITY AND STANDARD NORTHERN RED OAK SEEDLINGS IN TENNESSEE

David S. Buckley[1]

Abstract—First-year performance of high-quality (HQ), high- quality cull (HQC) and standard (ST) northern red oak (*Quercus rubra*) nursery seedlings was compared in a study established in a recent clearcut in mid-March, 2000. Objectives were to test effects of 1) seedling type, 2) planting treatment, and 3) control of competitors on the growth, browsing, and survival of planted seedlings. HQ, HQC, and ST northern red oak nursery seedlings averaging 109, 58, and 23 centimeters in height, respectively, were planted in three planting treatments: 1) row planting, 2) random spacing, and 3) inter-planting with loblolly pine (*Pinus taeda*). Three of 6 replicates for each planting treatment were chosen at random to receive competition control. Analyses within seedling types indicated no statistically significant differences between planting and competition control treatments in the first year. Differences between seedling types were much stronger. Height growth of HQ and HQC seedlings was significantly greater than that of ST seedlings. However, the incidence of browsing of HQ and HQC seedlings was also significantly greater than that of ST seedlings. Mortality of ST seedlings was significantly greater than HQC seedlings, but not significantly greater than HQ seedlings. It remains to be seen whether HQ seedlings will maintain their advantage over HQC and ST seedlings with continued browsing, and whether differences between planting and competition control treatments will strengthen as vegetation development and browsing continues.

INTRODUCTION

Artificial regeneration of oak can alleviate several problems during the early stages of regeneration such as insufficient seed sources, acorn predation, poor germination conditions, and heavy competition. Artificial regeneration with HQ seedlings can also be used to improve the quality of oak in stands where various forms of mismanagement have taken place. HQ or "super" oak nursery seedlings represent a promising alternative to ST seedlings for artificial regeneration. Seedling characteristics such as the number of coarse lateral roots and the overall size of shoots and roots are thought to be correlated with increased survival and competitive ability of oak seedlings after outplanting (Kormanik and others 1995, Kormanik and others 1997, Zaczek and others 1997). Relationships between nursery practices and these characteristics have been investigated, and protocols have been developed for producing seedlings that meet desired criteria (Kormanik and others 1994). Further, it has been demonstrated that high- and low-quality seedling grades can be distinguished visually prior to planting (Clark and others 2000). While progress has been made in defining and producing HQ oak planting stock, studies addressing the performance of different grades of seedlings are limited in number(for example Gordon and others 1995, Gottschalk and Marquis 1983, Zaczek and others 1997). Fewer still (for example Kormanik and others 1997) have documented outplanting results for HQ oak seedlings produced by the protocol developed by Kormanik and others (1994).

Potential limitations to the performance of HQ seedlings after outplanting are heavy competition with other woody vegetation and white tailed deer (*Odocoileus virginianus*) browsing. Intense competition with hardwood stump sprouts and fast-growing species arising from seed may affect the development of HQ oak seedlings, despite their large size and competitive potential (Kormanik and others 1997). Herbivory may compromise the competitive ability of any plant species (Louda and others 1990) and deer browsing can combine with heavy competition to have a synergistic, negative effect on survival. Experiences with outplanting oak nursery seedlings in Tennessee and several other regions indicate that deer have a high affinity for nursery seedlings (Buckley and others 1998, Gordon and others 1995, Kormanik and others 1995, Teclaw and Isebrands 1991). Fertilization of nursery stock may make freshly planted nursery seedlings more nutritious than the surrounding native vegetation. Controlling deer browsing is essential to establishing HQ oak plantings in areas with high deer populations. Repellants, tree shelters, and fencing methods have been developed for guarding against deer damage (Craven and Hygnstrom 1994, Nolte and Otto 1996). Unfortunately, the effectiveness of some repellants appears to depend on what other forage is available, and the costs of tree shelters and fencing can be prohibitive.

An alternative means of reducing deer browsing may be modified planting techniques that take advantage of

[1]Assistant Professor, University of Tennessee, Agricultural Experiment Station, Department of Forestry, Wildlife and Fisheries, P.O. Box 1071, Knoxville, TN 37901-107.1

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

relationships between deer foraging behavior, the spatial arrangement of seedlings, and structure formed by the surrounding vegetation. In prior studies conducted in Michigan, differences in the incidence of browsing of planted oak seedlings were documented over short distances with differences in vegetation structure (Buckley and others 1998). Browse damage of planted seedlings was far less frequent and intense in rows where red pine (*Pinus resinosa*) seedlings were inter-planted with northern red oak seedlings, and wherever competing vegetation partially or completely obscured a planted seedling. These observations warrant further investigation, and indicate that modification of the spatial and structural aspects of standard planting techniques may help reduce browsing losses.

OBJECTIVES

Objectives of this study were to: 1) Compare survival, growth, and browsing of 1-0 HQ northern red oak seedlings,1-0 HQC seedlings, and 1-0 ST seedlings planted in a recent clearcut in East Tennessee, 2) Investigate effects of controlling woody competitors on survival, growth, and browsing of each type of seedling, and 3) Test the viability of reducing deer browsing of planted seedlings by planting in a random pattern as opposed to a row pattern, and by inter-planting oak and loblolly pine.

METHODS

This study was established in a one-year old clearcut on the University of Tennessee Forestry Experiment Station, located near Oak Ridge in the Ridge and Valley Province of East Tennessee. All plots were located on the upper half of a north-facing slope. Site productivity was intermediate, and northern red oak formed a component of the stand prior to harvesting. Plots were laid out in an east-west line parallel to the edge of the adjoining unharvested stand (located up slope) to minimize bias in the entry of plots by deer, and spatial relationships with surrounding forest and landform features (figure 1). A 12.2 meter buffer zone was maintained between the unharvested stand edge and the upper margin of each plot (figure 1). A 7.3 meter buffer zone was maintained between all plots (figure 1.).

Six treatment combinations consisting of competition control or no competition control combined with a row planting pattern, a random planting pattern, and a row planting pattern where oak seedlings were inter-planted with loblolly pine were assigned at random to 3.7 x 16.5 meter plots (figure 1). Each treatment combination was replicated 3 times for a total of 18 3.7 x 16.5 meter plots in the study. A deer exclosure containing a row and an inter-planted plot was installed on the east end of the clearcut (figure 1) to allow comparisons of planted oak performance and vegetation development without any browsing.

Row plots contained 30 northern red oak seedlings planted in 3 rows on a 1.8 m spacing. Random plots contained 30 oak seedlings planted in a random pattern. Inter-planted plots contained 30 oak seedlings in 3 rows on a 1.8 meter spacing, inter-planted with loblolly pine seedlings. In the inter-planted rows, a 1-0 loblolly pine seedling was planted on both sides of each oak, 0.5 meter from the oak seedling stem (figure 1). All plots received 15 HQ northern red oak seedlings, 5 HQC seedlings, and 10 ST northern red oak seedlings. All seedling types were bare-root, 1-0 seedlings. HQ northern red oak seedlings from 5 genetic families were assigned to planting locations within plots in incomplete blocks to address potential interactions between slope position and performance of each family. HQC and ST seedlings were assigned to remaining locations at random. Both HQ and HQC seedlings were raised in the Flint River Nursery operated by the Georgia Forestry Commission in Montezuma, GA according to a protocol developed for producing HQ oak seedlings (Kormanik and others 1994). HQ and HQC seedlings were distinguished based on the number of first-order

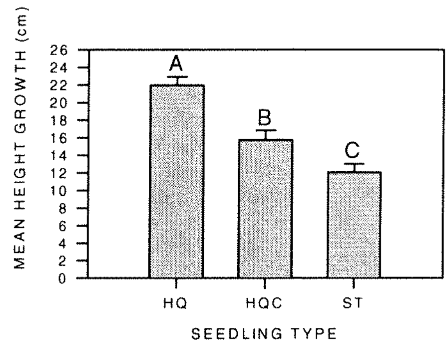


Figure 2—Mean 2000 height growth by seedling type. Means with different letters are significantly different based on ANOVA and Tukey's HSD at the α = 0.05 level. Error bars represent 1 S.E.

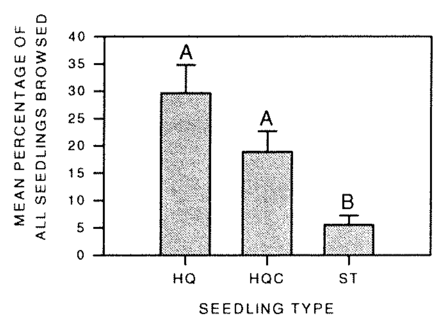


Figure 3—Mean percentage of seedlings with any type of browse damage in 2000 by seedling type. Indication of significant differences, tests, and error bars as in figure 2.

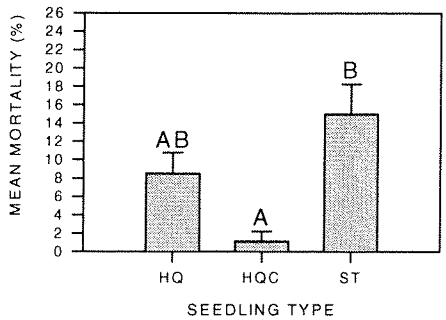


Figure 4—Mean 2000 percent mortality by seedling type. Indication of significant differences, tests, and error bars as in figure 2.

lateral roots, root collar diameter, and height (Clark and others 2000). ST seedlings were nursery-run seedlings obtained from a Tennessee nursery. Mean heights of HQ seedlings, HQC seedlings, and ST seedlings at the time of planting were 109, 58, and 23 centimeters, respectively.

Planting was completed March 20-22, 2000. Northern red oak seedlings were planted with a 20 centimeter diameter auger mounted on a 4-wheel drive tractor. Loblolly pine seedlings were planted with planting bars. No supplemental watering was used.

Woody and herbaceous competitors of oak seedlings were sprayed with glyphosate August 10-15, 2000 in all competition control plots. Oak seedlings were shielded during spraying to reduce potential damage due to drifting spray. Competition control treatments will be repeated in subsequent growing seasons.

Initial height of all planted oaks was measured between the soil surface and the tip of the terminal bud on the dominant leader. Height growth for the first growing season was determined by remeasuring heights in the same manner as described above on October 10, 2000. Seedlings were tallied for bud break and development of the first growth flush on May 5, 2000 and again on June 9, 2000. Damage due to deer browsing was recorded on June 9, July 21, and October 19, 2000. Both the presence of browsing and the type of browsing (terminal leader, lateral branch, or a combination) were documented. Mortality was recorded on the same dates as browsing. Seedlings were considered dead when shoots were completely missing, or when no live buds or green inner bark could be found on stems and at the root collar.

Preliminary analyses run within seedling types indicated no statistically significant effects of planting and competition control treatments at the α = 0.05 level. Thus, differences between seedling types in growth, browsing, and mortality were analyzed through ANOVA and Tukey's HSD using data pooled over planting and competition control treatments.

RESULTS

Although planting and competition control treatment effects were not statistically significant, there was a trend toward slightly greater growth of HQ seedlings in plots receiving competition control. There were also trends toward a slightly lower incidence of browsing of HQ and HQC seedlings in inter-planted plots than in row and random plots, and toward greater mortality of seedlings with competition control than without.

Much stronger differences occurred between seedling types in phenology, growth, browsing, and mortality. HQ seedlings flushed later than HQC and ST seedlings. Only 62 percent of HQ seedlings had broken bud by May 5, 2000, compared with 98 and 97 percent of HQC and ST seedlings, respectively. Mean height growth of HQ seedlings was significantly greater than that of HQC and ST seedlings (figure 2). Mean height growth of HQC seedlings was significantly greater than that of ST seedlings, but significantly less than that of HQ seedlings (figure 2).

The mean percentages of HQ and HQC seedlings that had any degree of deer damage were significantly greater than the mean percentage of ST seedlings showing browse damage (figure 3). As was the case for height growth, browsing of HQC seedlings was intermediate between browsing of HQ and ST seedlings. As of June 9, 2000, 76 percent of HQ seedlings sustaining browse damage had damage to the terminal leader, while browsing of terminal leaders occurred in 100 percent of HQC and ST seedlings.

October mean percent mortality of ST seedlings was significantly greater than mortality in HQC seedlings, but not significantly greater than HQ seedlings (figure 4). Although differences between planting and competition control treatments were not statistically significant, mean percent mortality of ST seedlings was highest (30 percent) in random plots receiving competition control. Twenty-seven percent of the HQ seedlings that died and 11 percent of the ST seedlings that died had experienced browsing. The single HQC seedling that died was also browsed.

DISCUSSION AND CONCLUSIONS

Limited vegetation development, limited loblolly pine seedling growth, and low levels of browsing and competition during the first growing season may account for the lack of statistically significant differences between planting and competition control treatments. Competition between planted seedlings and other herbaceous and woody plants is expected to increase with time as stump sprouts and other vegetation continue to develop. Similarly, the impact of competition control treatments should increase as well. The 1-0 loblolly pine seedlings planted likely had little effect in shielding the larger planted oaks from browsing due to their small size. Loblolly pine seedlings were only half the height of most HQ oak seedlings during the 2000 growing season. Browsing was also lighter than expected.

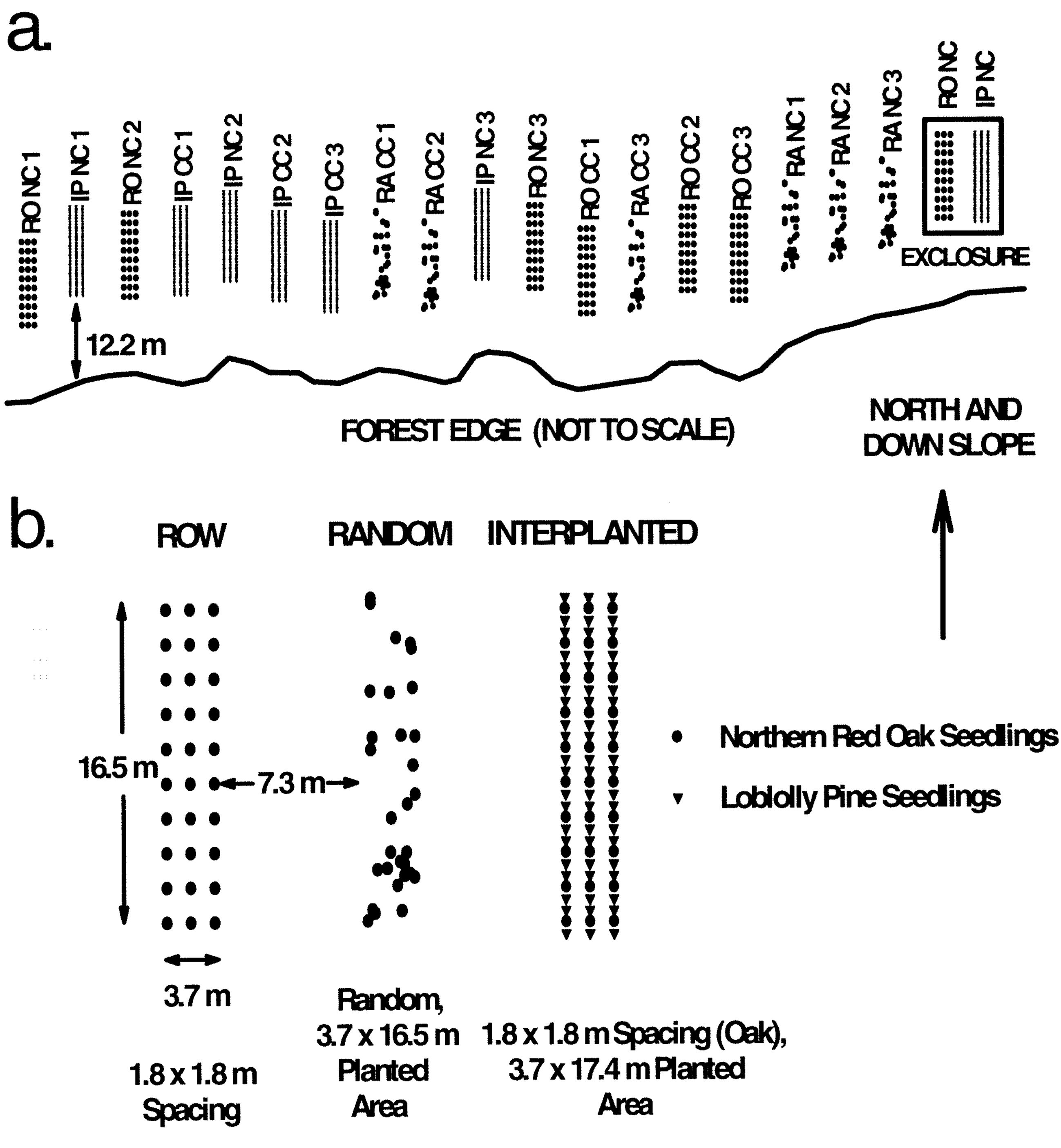


Figure 1—Layout of study (a) and planting patterns (b). RO = row, RA = random, IP = inter-planted. CC = competition control and NC = no competition control. Each plot contains 15 HQ seedlings, 5 HQC seedlings, and 10 ST seedlings.

The patterns in height growth between seedling types observed were consistent with previous predictions (Kormanik and others 1995). Mean height growth of HQ, HQC, and ST seedlings appeared to be closely correlated with seedling height at the time of planting. However, differences in nursery practices, stem diameter, the number of first-order lateral roots, and overall biomass could have contributed to these differences as well.

Differences between seedling types in the incidence of deer browsing may be related to differences in apparency and nutritional value. In contrast to ST seedlings, the shoots of HQ and HQC seedlings often extended well above competing vegetation. This difference in canopy position may have resulted in much greater apparency of HQ and HQC seedlings to deer. Similar effects of understory vegetation have been reported previously (Buckley and others 1998, Gottschalk and Marquis 1983). More frequent browsing of HQ and HQC seedlings may also be related to greater nutritional value imparted by the HQ nursery protocol.

Several factors may have contributed to seedling mortality: poor microsites, competition, browsing, and overspray of glyphosate. All seedlings were susceptible to potentially poor microsite conditions and competition prior to application of the competition control treatment. Browsing may have played a role in the mortality of a percentage of seedlings, particularly HQ seedlings. Accidental application of glyphosate killed several small ST seedlings hidden by vegetation in plots receiving competition control, particularly in random plots.

Based on first-year results, HQ seedlings appear most promising in terms of growth, although survival was greatest for HQC seedlings. The consequence of the heavier browsing experienced by HQ seedlings remains an important question. Whether these seedlings are successful in rapidly escaping the reach of deer, or whether repeated browsing will compromise their advantage over ST seedlings is unknown. Browsing may be of minimal importance on some sites, but deer populations are increasing in parts of Tennessee and elsewhere. It also unclear whether effects of planting and competition control treatments will strengthen. Long-term monitoring of seedling performance is planned.

ACKNOWLEDGMENTS

I thank Scott Schlarbaum for supplying seedlings, and Richard Evans and his crew for helping implement the study. I also thank Brien Ostby, Leslie Chadwell, Chad Christman, and Jason Willis for their help in planting and in data collection. This work was supported by McIntire-Stennis funds.

REFERENCES

Buckley, D.S.; T.L. Sharik; J.G. Isebrands. 1998. Regeneration of northern red oak: Positive and negative effects of competitor removal. Ecology 79: 65-78.

Clark, S.L.; S.E. Schlarbaum; P.P. Kormanik. 2000. Visual grading and quality of 1-0 northern red oak seedlings. Southern Journal of Applied Forestry. 24: 93-97.

Craven, S.R.; S.E. Hygnstrom. 1994. Prevention and control of wildlife damage: deer. In Hygnstrom, S.E., R.M. Timm, and G. Larson. 1994. Prevention and control of wildlife damage. University of Nebraska Cooperative Extension; Great Plains Agricultural Council, Wildlife Committee; and USDA Animal and Plant Health Inspection Service, Animal Damage Control.

Gordon, A.M.; J.A. Simpson; P.A. Williams. 1995. Six-year response of red oak seedlings planted under a shelterwood in central Ontario. Canadian Journal of Forest Research. 25: 603-613.

Gottschalk, K.W.; D.A. Marquis. 1983. Survival and growth of planted red oak and white ash as affected by residual overstory density, stock size, and deer browsing. In Muller, R.N., editor. Proceedings of the Fourth Central Hardwood Forest Conference, Lexington, Kentucky, November 8-10, 1982. University of Kentucky, Lexington, KY. 125-140.

Kormanik, P.P.; S.S. Sung; D.J. Kass; S.Schlarbaum. 1997. Effect of seedling size and first-order-lateral roots on early development of northern red oak on mesic sites. In: Waldrop, T.A., ed. Proceedings of the Ninth biennial southern silvicultural research conference; 1997 February 25-27, Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 247-252.

Kormanik, P.P.; S.S. Sung; T.L. Kormanik. 1994. Toward a single nursery protocol for oak seedlings.In: Proceedings of the 22nd Southern Forest Tree Improvement Conference; 1993, June 14-17; Atlanta, GA: 89-98.

Kormanik, P.P.; S.S. Sung; T.L. Kormanik; S.J. Zarnoch. 1995. Oak regeneration – why big is better. In: National Proceedings of Forest and Conservation Nursery Association. Ft. Collins, CO: USDA Forest Service Pacific Northwest Experiment Station Gen. Tech. Rep. PNW-365: 117-123.

Louda, S.; K.H. Keeler; R.D. Holt. 1990. Herbivore influences on plant performance and competitive interactions. 413-444 p. In Grace, J.B., and D. Tilman, editors. Perspectives on plant competition. Academic Press, New York. 413-444.

Nolte, D.L.; I.J. Otto. 1996. Materials and supplies for management of wildlife damage to trees. U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center Tech. Rep. 9624-2808-MTDC. 48 p.

Teclaw, R.M.; J.G. Isebrands. 1991. Artificial regeneration of northern red oak in the Lake States. In: Laursen, S.B.; J.F. DeBoe, eds. The oak resource in the upper Midwest: implications for management; 1991 June 3-6; St. Mary's College, Winona, MN: Publication number NR-BU-5663-S, Minnesota Extension Service, University of Minnesota, St. Paul, MN.

Zaczek, J.J.; K.C. Steiner; T.W. Bowersox. 1997. Northern red oak planting stock: 6-year results. New Forests 13: 177-191.

CONTAINER SIZE AND FERTILIZATION AFFECT NURSERY COST AND FIFTH-YEAR FIELD PERFORMANCE OF CHERRYBARK OAK

Kirk D. Howell and Timothy B. Harrington[1]

Abstract—Successful regeneration of bottomland hardwoods relies on the production of vigorous, plantable, and affordable stock by commercial nurseries. To quantify nursery cultural influences on subsequent field performance of cherrybark oak (*Quercus pagoda* Raf.), seedlings were grown in a greenhouse in small, medium, or large containers for three months with or without fertilization. In December 1994, seedlings were planted at a bottomland site near Milledgeville, GA with or without removal of the container soil as a method to reduce transport and planting costs. Estimated costs per thousand seedlings for these practices were about $1225, $560, and $185 for large, medium, and small containers, respectively. A 30 percent profit margin was added to each price. The incremental cost of fertilization per thousand seedlings was about $12, $6, and $2 for large, medium, and small treatments, respectively. Cost savings from container soil removal were substantial for the large containers, and savings decreased with decreasing container size. Five years after planting, survival of seedlings from large containers (97 percent) was significantly greater than that from small containers (85 percent). Soil removal was associated with reductions in seedling survival, but only in the absence of fertilization. Stem diameter and height of seedlings from small containers were less than those of seedlings from medium and large containers, and they were also significantly greater in the presence versus absence of fertilization. Fifth-year seedling size did not vary significantly between levels of soil removal. Nursery and fifth-year cost efficiencies were greatest for fertilized, soil removed, medium containers and for fertilized, small containers.

INTRODUCTION

Large seedlings are recommended for successful artificial regeneration of oak (Ruehle and Kormanik 1986), but high cost and difficulty of planting them can greatly limit cost effectiveness and applicability of this method of regeneration. Poor performance of planted oaks probably reflects the need for improvements in both nursery and planting technology. It is one thing to grow an ideal oak seedling to a sapling size in one or two years, but then to correctly plant the proportional root mass can impose quite the endurance test (Bowersox 1993). Planting speed and quality under these conditions can be compromised, especially when specifications require holes in difficult soils greater than 15 centimeters depth. Large seedlings with proportionately sized root systems cannot be correctly and efficiently planted unless they are undercut at lifting, root-pruned at the time of planting, or the planting hole is of sufficient size to accommodate the extensive root system. Unless root alteration is performed, planting seedlings with roots larger than the hole will result in either root deformation (Haase *et al.* 1993) or root desiccation because of shallow planting.

The field applicable alternative may best be found in root confinement, rather than in root alteration -, i.e., growing seedlings with root systems designed to fit the planting tool, instead of reducing the size of the root system to accommodate the planting tool. The former attempts to prevent rooting excess, while the latter attempts to correct the problem. Containerized seedlings have shown success in survival and growth, and a further incentive of root confinement should be to facilitate the planting of large stems. Another incentive for containerizing seedlings is to permit managers to plant late into the season, and to maintain more of a three-dimensional root configuration after planting.

It is not clear how containerized seedlings will fare when planted as bareroot stock, or how such procedures will affect cost of planting or nursery production. In an attempt to address these issues, a study on cherrybark oak was initiated to compare field performance, associated costs of nursery production and planting, and cost efficiency of among treatments that included differences in container size, nursery fertilization, and removal of container soil at the time of planting.

MATERIALS AND METHODS

In a greenhouse on the University of Georgia campus, Athens GA, seeds of cherrybark oak were sown July 1994 in small, medium, or large containers (3.5, 6.5, and 11.5 centimeter diameters, respectively) and grown for 3 months. A randomly selected half of the seedlings received a weekly fertilization treatment with a water solution of 20N 20P 20K. A total of 100 seedlings were

[1]Regeneration Forester, Ph.D. candidate, Department of Forest Resources, Clemson University, Clemson, SC 29634-1003
Associate Professor, Daniel B. Warnell School of Forest Resources, University of Georgia, Athens, GA 30602-2152, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

cultured for each of the six treatments (three container sizes x two fertilization levels). In October 1994, seedlings were moved to an open-air enclosure to stimulate the onset of dormancy. The planting site, a 0.1-hectare area fenced to prevent deer browse, is located on an abandoned field in the lower flood plain of the Oconee River near Milledgeville Georgia. Competing vegetation was suppressed with a broadcast application of a 2 percent water solution of Accord® (glyphosate) herbicide in July 1994. Prior to planting, seedlings were randomly assigned to either removal or retention of container soil as a test to reduce transport and planting costs. In December 1994, seedlings were planted with a hoedad at a spacing of 0.5 x 1.8 meters. The experimental design is completely randomized with three replications of 13 seedlings for each of the twelve treatments, a total of 468 seedlings. Survival, basal stem diameter, and height of each seedling were measured one, two, three, and five years after planting. A per-hectare value of total stem volume (cubic decimeters) was calculated for each treatment replication assuming a planting density of 750 seedlings per hectare.

The retail price required to produce a thousand seedlings was estimated for each treatment using real cost information from an undisclosed nursery. The price equaled the seedling cost at planting plus the cost of planting. We assumed a nursery that contained 7500 square meters of production space (15 greenhouses). Container diameter determined capacity of container production. Fixed costs, including salaries, insurance, dues, research and development, land, buildings, and supplies, were assumed to be influenced by greenhouse capacity. Treatment-related costs included fertilizer and application costs, labor and materials for packaging, transport and storage of seedlings as affected by container size, and labor and materials associated with container soil removal. The price per thousand seedlings included 30 percent profit. Field costs, such as the purchase price of land and costs of site preparation, were not included in this analysis. Costs were compounded for five years assuming an eight percent interest rate. The ratio of nursery cost (dollars per hectare of planted seedlings) to stem volume yield (cubic decimeters per hectare) was calculated to provide an index of cost efficiency.

RESULTS AND DISCUSSION

In the nursery, we achieved almost 100 percent stocking of growing space. Five years after planting, survival of seedlings from large containers (97 percent) was significantly greater than that from small containers (85 percent). Unfertilized, soil intact seedlings were also significantly lower in numbers (83 percent) as compared to the other treatment combinations, which is to be expected from nutrient deficient seedlings, but these results seem counterintuitive since the soil was left intact. From the nursery, fertilized seedlings from large and medium containers were significantly greater in diameter (4 millimeters), height (32 centimeters), and yield (2.2 cubic decimeters per 1000). Seedlings from the large and medium container sizes remained significantly larger than those from small containers by year one, and as expected, fertilized seedlings remained significantly larger than those not fertilized. By year five, fertilized seedlings from large and medium containers remained significantly greater in diameter (43 millimeters), height (338 centimeters), and yield (1.84 cubic meters per hectare). Initial stem diameters (< 5 millimeters) and heights (< 50 centimeters) were smaller than those currently recommended for artificial regeneration (Ruehle and Kormanik 1986).

Full stocking of growing space in the nursery seedbed or in the field is critical if costs are to be minimized. Increasing seedbed density or maintaining survival favors the cost side of the equation. All fixed costs (wages, salaries, investments, etc.) were to be recovered in the pricing of the product. The fixed costs to grow 600,000 stems in large size containers carried a relative charge per thousand seedlings of $1003, $451 to grow 1,333,000 stems in medium size containers, and $142 to grow 4,267,000 stems in small size containers. Since there was near 100 percent stocking in the nursery, the quantity sown was the quantity harvested. If stocking had been less, nursery fixed costs would have increased to cover this shortfall.

Variable costs, also affected by the quantity supplied, were most influenced by fertilization and soil removal. Fertilization had little impact with values of $12, $6, and $2 per 1000 seedlings for large, medium, and small treatments, respectively, representing the combined supply and application costs of fertilization. Regardless of the capacity, the cost of fertilization is a small price to pay for the yield increase resulting from it. Soil removal, on the other hand, displayed the greatest cost impact on materials saved. Soil and amendment costs were calculated by determining the cost required to replace either 100 percent of the material (soil intact), or 10 percent of the material (soil removed) every year for each container size treatment. At $1 for every 50 pounds of material, the relative costs figured to be $28, $30, and $24 per 1000 seedlings for large, medium, and small soil intact treatments, respectively, but only 10 percent of these costs were charged when soil was removed. The assumption is that sterilized soil and amendments will be reused from year to year in the soil-removed situation, and only 10 percent of which needs to be replaced.

Seed sowing costs were affected by the time required to sow seed into containers. Relative times in seconds to prepare and fill 20 containers with soil and to sow seed were about 320, 200, and 120 seconds for large, medium, and small containers, respectively, which translates into a sowing cost of $45, $27, and $18 per thousand, respectively. The rate of pay to the laborer was determined to be $10 per hour, and this wage remained the same with all operations involving the use of time.

Nursery transport costs were calculated according to the amount of time required to move a load 100 feet in three minutes, and transporting in the nursery was performed in two trips (from the head house to the greenhouse position after sowing, and from the greenhouse to the packing house at harvest time). The cost per 1000 seedlings to move large containers was calculated to be about $56 with nine containers per trip, about $25 with 20 medium containers per trip, and about $10 with 50 small containers per trip.

Packing materials were affected by the relative size of seedlings and whether or not soil was left intact. The amount of seedlings to equal 30 pounds was the criteria utilized, and thus the heavier the seedling, the larger the quantity of bags required. The cost of bags ($1) includes the costs involved in the packaging operation. All soil removal treatments, regardless of container size, carried a similar bag charge (about $2 per 1000 seedlings), with an average of 500 seedlings per bag. However, packing costs with heavier, soil intact seedlings were about $80 per 1000 seedlings for the large, $39 for the medium, and $10 for the small container sizes.

The total nursery costs (fixed and variable) were figured to be about $1225, $560, and $185 per 1000 seedlings for large, medium, and small containers, respectively. With the additional 30 percent profit margin included for pricing each treatment, the values increased to about $1590, $730, and $240 per 1000 seedlings for large, medium, and small containers, respectively. Prices became the relative costs of the seedlings purchased for planting. Thus, to express seedling price per hectare, reduce the nursery seedling price by 25 percent (assuming 750 stems per hectare).

The planting operation involved the cost of carrying seedlings to their respective positions to be planted (determined by the weight of the load) and the time (seconds per seedling) it required to plant them. Each of these integrated tasks (involving weight and time) in the planting operation was equally allocated. The wage paid to the worker in the field was $15 per hour, as opposed to the $10 per hour nursery wage. Each soil removal treatment, regardless of container size, carried similar costs for planting, with a fifth year of compounded cost of $25 per hectare. Treatments with soil left intact, however, constrained the planting operation to differ greatly with container size, with fifth year costs of about $139, $85, and $34 per hectare for large, medium, and small container sizes, respectively. Removing soil from the seedlings of small container does not offer the same reduction in planting costs as it does from those seedlings of medium and large containers.

There were other plantation costs that could be assessed, e.g., site preparation and land costs, but these types of costs were not factors in our study because they had no influence on our treatments. Therefore, total fifth-year plantation costs, involving only the cost of seedlings and planting them, were about $1335, $630, and $220 per hectare for large, medium, and small container sizes, respectively.

The nursery treatments having the greatest cost efficiency were those of medium, fertilized, soil removed ($277 per cubic decimeter), and small, fertilized ($247 per cubic decimeter). Fifth-year results indicated similarly the lowest values of cost efficiency for fertilized, soil removed, medium containers ($285 per cubic meter), as for fertilized, small containers ($272 per cubic meter). It is interesting to note that the large, fertilized, soil removed treatment by year five was great enough in yield (2.47 cubic meters per hectare) to overcome a relatively large seedling and planting cost ($1261 per hectare), and displayed a cost efficiency ($510 per cubic meter) almost equal to that of the unfertilized, small containers ($468 per cubic meter). This illustrates how excellent seedling performance from expensive seedlings can, after five years, "catch up" with inexpensive seedlings that have lagged in growth.

CONCLUSION

Successful artificial oak regeneration involves many factors that carry both cost and yield implications. Representation, both in the nursery and in the field, is a critical factor which deals with the quantity supplied to the market, dictating the price to be attached to the product (Tomek and Robinson 1990). The productivity of an operation, which we have attempted to demonstrate here, can be increased by: 1) increasing seedling density in the allocated space; 2) improve percent emergence after sowing; and 3) maintain high survival percentages after germination or after planting in the field. However, It has been shown in this study, as in others (South 1993), that stem diameter is typically reduced when seedlings are grown at high densities, and this has an impact on long-term plantation success.

The quality of the product, other than the genetic properties, was expressed in terms of seedling size or stem yield (i.e., proportional allocations of mean diameter and height were described in the stem volume equation), but quality cannot be completely evaluated without attempting to evaluate the entire process of production. Stem yield is much easier to describe and evaluate statistically, than is the estimation of the costs associated with production, which may explain why cost accounting is often avoided. This is acceptable when the study is strictly biological. In this study of applied science, however, hypothetical cost estimation involved many cost assumptions (e.g., costs of labor, nursery space, supplies, etc.). Assumptions can be most credible when derived from empirical operations, and our estimates for each treatment utilized real cost information from an undisclosed nursery. It was where no operation or empirical data exists that values must be derived from factors of time, volume or weight. Valuation must be revised, therefore, from time to time, place to place, and according to current knowledge.

While the small and medium, fertilized treatments were optimum in cost efficiency, the large, fertilized, soil removed treatment showed great promise in overcoming the excessive costs. The cherrybark oak benchmarks established here have shown fifth-year yield results that could arguably be considered morphologically eight years old according to plantation standards (Kennedy 1993), or ten years old when grown under natural conditions. Moreover, this benchmark offers a challenge to future research to produce the same or better yield, and also to eliminate any extreme costs attached to production (Howell 2002). We have yet to accurately and completely test the limits of nursery and plantation cost efficiency.

When one wishes to compare studies from place to place or from time to time, other costs pertinent to production must be evaluated. Protecting the seedlings in our study was cost prohibitive in practice (several thousand dollars per hectare depending on the materials used), and the inclusion of costs like this can dilute the gains perceived. Nevertheless, one could argue that expensive, and perhaps non-applicable, methods must be eliminated to promote large-scale regeneration of cherrybark oak.

As natural oak stands are depleted and the demand for oak products rise, there will be an increased emphasis toward higher productivity on a given land base. If land owners or managers are to invest in the oak stand, confidence must be established that vigorous stems will be efficiently purchased and planted, that costly procedures will not be required to ensure survival, and that steady growth will secure high future stem yield and plantation success.

ACKNOWLEDGMENTS

The authors would like to thank T&S Hardwoods for the donation of land and resources. Appreciation is also expressed to J. Brown for the time utilized in looking after the seedlings of this study.

REFERENCES

Bowersox, T.W. 1993. Artificial regeneration of oaks in the uplands. In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: serious problems, practical recommendations: Symposium proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 250-263.

Haase, D.L.; J.H. Batdorff; R. Rose. 1993. Effect of root form on 10-year survival and growth of planted Douglas-fir trees. Tree Planter's Notes. Vol. 44, 2: 53-57.

Howell, K.D. 2002. Cherrybark oaks from perforated containers planted as bareroots with open-grown oak bareroots. [This proceedings].

Kennedy, H. 1993. Artificial regeneration of Bottomland Oaks. In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: serious problems, practical recommendations: Symposium proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 241-249.

Ruehle, J.L.; P.P. Kormanik. 1986. Lateral root morphology: a potential indicator of seedling quality in northern red oak. Research notes SE-344. U.S. Department of Agriculture, Forest Service.

South, D. B. 1993. Rationale for growing southern pine seedlings at low seedbed densities. New Forests 7: 63-92.

Tomek, W. G.; K. L. Robinson. 1990. Agricultural Product Prices. Third Edition. Cornell University Press. Ithaca, New York. 360 p.

EFFECT OF SEEDLING SIZE AND FIRST-ORDER LATERAL ROOTS ON EARLY DEVELOPMENT OF NORTHERN RED OAK ON A MESIC SITE: ELEVENTH-YEAR RESULTS

Paul P. Kormanik, Shi-Jean S. Sung, Donald Kass, and Stanley J. Zarnoch[1]

Abstract–The effect of initial first-order lateral root (FOLR) groupings of northern red oak (*Quercus rubra*) seedlings on a high quality mesic site was followed for eleven years on a shelterwood and a clearcut area. The initial FOLR number groups were empirically determined as low (0 to 6), medium (7 to 12), and high (12). The shelterwood overstory was removed before the beginning of the eighth growing season and a circle (0.9 meter radius) was released around individual oaks in the clearcut. Individuals in the clearcut responded favorably to release, with some obtaining 6 to 8 meter in height by age 11. After the same period mean height from the shelterwood plantings was about 60 centimeter more than their initial height in 1990. It appears that large thrifty northern red oak seedlings can be established in properly controlled clearcut areas provided post harvest control of stumps is completed in a timely fashion. The shelterwood system with artificial regeneration does not appear to be a viable regeneration alternative as tested here.

INTRODUCTION

The basic tenets for northern red oak (NRO) (*Quercus rubra*) regeneration have been described by Sanders (1971, 1972). Working on lower quality sites in the central states, he clearly established that successful regeneration depended almost exclusively on the presence of advanced oak reproduction when the mature stand was harvested. On sites where the research was completed, faster growing competing species were a minor problem at best. However, obtaining the necessary advanced oak reproduction proved to be time consuming and difficult. Research after Sanders' was directed at various methods of obtaining adequate advanced reproduction by attempting to combine both natural and various combinations of artificial regeneration (Johnson 1993, Loftis 1983). This later research was applied to high quality mesic sites as well as sites comparable to those on which Sanders' research was completed. The use of the shelterwood system to encourage the development of advanced natural regeneration became the norm on these higher quality sites as clearcutting in any form became vilified by many uninformed individuals. In addition, various combinations of root/top pruning of nursery stock were extensively tested to improve their growth performance and, to increase the number of NRO after shelterwood was removed.

Eventually, it became apparent that competition from faster growing species made it very difficult to maintain a viable presence of NRO on the desirable mesic sites and NRO's future on these sites became questionable (McGee and Loftis 1986). Kellison (1993) most recently suggested that if new technology was not soon developed then NRO may become the "California Condor" of the eastern deciduous forests.

The initial objective of this research was directed at determining whether the nursery fertility protocol developed at our research center could produce "advanced oak regeneration" in the nursery in a single growing season. A secondary objective was to determine if a first-order lateral root (FOLR) grading systems previously used for sweetgum could be modified to select the best oak seedlings for outplanting in both a clearcut and shelterwood operation on a high quality mesic site.

METHOD

Two adjacent areas on the USDA Forest Service's Grandfather Ranger District on the Pisgah National Forest, 12 miles northwest of Marion, NC, were used in this study. The site index for yellow poplar (*Lirodendron tulipfera*) was approximately 100 (base age 50). The main crown canopy was a mixture of northern red oak, white oak (*Q. alba*), red maple (*Acer rubrum*), and yellow poplar. The clearcut area to be used for NRO enrichment planting was a small segment of a larger harvested area. The shelterwood area

[1]Principle Silviculturist and Research Plant Physiologist, Institute of Tree-Root Biology, USDA Forest Service, 320 Green Street, Athens, GA.; Project Forester, Technical Development Unit, N.C. Division of Forest Resources, Morganton, NC 28655; Station Mathematical Statistician, USDA Forest Service, 200 Weaver Boulevard, Asheville, NC 28802, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

was immediately across the road from the clearcut area and had essentially the same species composition. For the underplanting, basal area was reduced by 30 percent to 20.44 meter^2/hectare, primarily by removing the intermediates and suppressed trees from the canopy level and all individuals occurring in the subcanopy level.

Acorns were collected from the Forest Service's Wataqua Seed Orchard in eastern Tennessee. The seedlings were grown at the Institute of Tree Root Biology's (ITRB) Whitehall Experimental Nursery, Athens, GA during the 1989 growing season, using a hardwood nursery protocol (Kormanik and others 1994). The seedlings were lifted during February 1990 and outplanted in March 1990. When lifted, the seedlings were placed in one of three groups, low, medium, and high, based upon FOLR numbers. First-order lateral roots were defined as roots with basal diameter exceeding 1 millimeter along the first 30 centimeter of taproot below the root collar. The low, medium, and high groups had FOLR numbers of 0 to 6, 7 to 11, and 12, respectively. Root collar diameters (RCD) and heights were recorded for each seedling. Each lateral root was trimmed to approximately 15 centimeter and taproots were pruned to 30 centimeter before seedlings were outplanted.

The clearcut and shelterwood areas were each considered as randomized block design. Eight blocks were laid across the contour in each of the two areas and 10 trees from each FOLR group were shovel planted at 1.5 meter by 3.1 meter spacing in adjacent rows. The spacing was maintained with only minor adjustments due to large stumps. All standing trees, regardless of size in the clearcut area were felled before planting but no subsequent vegetation control measures were taken until the seventh growing season. Mechanical control in the shelterwood area removed all subcanopy trees as well as specific canopy trees overlapping naturally regenerated northern red oak seedlings on the periphery of the planted area. No subcanopy oak was present, but none of the naturally regenerated oak in the main canopy was removed when shelterwood was established. No statistical analyses were performed to compare clearcut with shelterwood because each was an independent randomized block experiment. In addition, no statistical comparisons were done for FOLR groupings due to the presence of stump sprouts and different degree of insect infestation between the two areas.

Survival data were obtained after the first growing season in 1990. Survival, RCD, and height were also obtained after the 5th year (1994) and potentially dominant individual oak in the clearcut were identified. Competing vegetation density was recorded from three positions in each block during the 5th year measurement. Five artificially regenerated trees were excavated after the 5th growing season from both the shelterwood and clearcut areas to examine root development characteristics.

All artificially established individuals in both areas were measured prior to the 7th growing season. In the beginning of the 7th growing season (1997), the clearcut was released with a silvicide by establishing circles of 0.9 meter radius around each remaining dominant or co-dominant planted NRO seedlings. The shelterwood release was delayed until the 8th year prior to the spring flush. Prior to crown removal, all surviving NRO seedlings were conspicuously identified by flagging on the stems and tags attached at ground line to permit post harvest identification. The felling was such that whenever possible the tops were felled toward the outer boundary in an attempt to minimize damage to the surviving seedlings. In winter following shelterwood removal and completion of one growing season, individuals were placed into six groups as follows: 1. dead; 2. undamaged; 3. top one-third stem damaged; 4. top two-thirds stem damaged; 5. stem missing, sprouting from root collar; and 6. stem flat on ground, sprouting along entire length. The entire study was re-measured at this time and again after 3 years post release in January 2001.

RESULTS AND DISCUSSION

Basically, even with supposedly high quality seedlings, the shelterwood method proved to be unsatisfactory on this high quality site. Comparable results have been reported and have resulted in the misconception that artificial regeneration is not a viable option for NRO on those quality sites (Johnson 1993, McGee and Loftis 1986).

Performance of NRO seedlings in the clearcut, was very good even after a very shaky beginning. Indeed, several unanticipated factors significantly affected this experiment. The first, was a massive infestation of the 17 year locust (*Magicicada septendecim*) that severely damaged almost all 240 seedlings in the clearcut toward the end of the second growing season. However, only the artificially regenerated oak seedlings in the clearcut were affected while none of the oak seedlings in the shelterwood were attacked. No other species were damaged by this locust infestaticn. The second factor was the intense competition from untreated stumps and newly germinated seedlings of Carolina silverbell (*Halesia carolina*), red maple, and yellow poplar in the clearcut which continued unabated throughout the pre-release seven growing seasons. The final item, occurred one year post harvest when a leaf mining maggot (*Agromyza viridula*) attached the newly emerging leaf of only the NRO individuals in the clearcut. These maggots essentially eliminated a growth response during the first year post release. In contrast, the individuals in the shelterwood were free of disturbing factors.

Seedling Survival

Survival following the first season was 100 percent in both the clearcut and shelterwood understory plantings for all three FOLR groups of seedlings (table 1). The second year, locust damage was so extensive on seedlings in the clearcut that their long term survival appeared to be in doubt. Many stems were severely damaged over half to two-thirds of their height and lost much of the height advantage over newly germinated competitor species. Mortality rate accelerated during the third season but

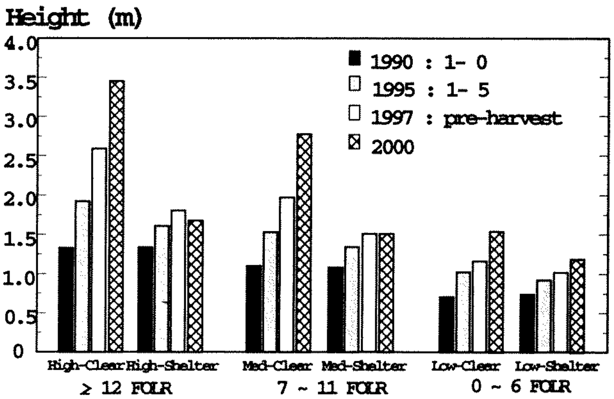


Figure 1–Percentage tree damage by grade in shelterwood planting after shelterwood removal.

stabilized by the initial re-measurement at age 5 (table 1). Seedling FOLR grouping really had no effect upon survival in the clearcut as survival was determined primarily by effects of the locust damage. Intense stump sprout competition also increased mortality in the clearcut site.

In the shelterwood most seedlings from all three FOLR groupings were intact at the 5th year measurement (table 1). A total of 20 trees had not survived in the shelterwood at age 5. Of these 20, 16 were low FOLR group, two in the medium group, and two in the high group. Survival remained relatively constant from the 5th to the 7th growing season for the high FOLR group but the individuals from the medium FOLR group were reduced in number to a greater extent than those from the clearcut (table 1). Survival did not change appreciably between the 5th and 7th year in the clearcut planting area. Release resulted in no accelerated mortality only for high group in the clearcut in the 11th year. Shelterwood removal resulted in considerable mortality in all three FOLR groupings. It also resulted in stem damage that is affecting the competitive potential of the surviving seedlings. The survival as well as the damage categories recognized after canopy removal are shown in figure 1. Less than one-third of the individual stems were undamaged and all others experienced considerable stem

Table 1—Northern red oak survival percentages by first-order lateral root groupings from clearcut and shelterwood plantings

	----------Clearcut-------			------Shelterwood-----		
Survival rate	High[a]	Medium	Low	High	Medium	Low
1st year	100	100	100	100	100	100
5th year	68	66	63	98	98	80
7th year	66	63	59	96	78	75
11th year	63	55	48	86	60	68

[a]High = 12; Medium = 7-11; Low = 0-6 first-order lateral root number.

damage that will in both the short and long-term affect their survival (figure 1).

Competitive Status of Natural Regeneration
Most of the naturally regenerated oak seedlings in the clearcut and shelterwood were less than 30 centimeter tall when the study was initiated and few were alive by age 7. Although we did not make an exhaustive survey, naturally regenerated NRO seedlings were rarely observed at year 7 or 11. We do not know whether this situation occurred due to limited mast production or insufficient sunlight for seedling development or both. In neither the shelterwood nor the clearcut, would natural northern red oak regeneration development have been sufficient for this species to be more than a minor or occasional component on this high-quality mesic site. Artificial regeneration in the clearcut has altered this possibility through at least age 11, and indicates artificial regeneration may play a role in maintaining a viable population of NRO on these high quality mesic sites.

Shelterwood

One of the objectives of a shelterwood is to limit sunlight that would encourage development of competing species yet provide sufficient sunlight for the NRO seedlings to become established. The original basal area reduction was effective through the 7th year, such that no low or mid-crown canopies had developed. However, even the high FOLR grade seedlings have not developed satisfactorily either before or post canopy removal. Height growth was minimal and RCD through the 5th year remained essentially unchanged from their initial caliper. The 7th year DBH measurements were unimpressive. The poor performance resulted in the decision to remove the shelterwood before the accelerating decline of individuals worsened. Prior to release, low FOLR group of seedlings was the smallest and they were spindly, although some of these above 1.0 meter might be considered "advanced" reproduction. (Loftis 1983, Sanders and Graney 1993). Characteristics of all shelterwood seedlings is that only a few leaves developed annually throughout the 7 years. Even on the largest seedling, seldom have we observed more than 20 to 30 leaves. Tip dieback has occurred several times on most of the seedlings but dieback to ground level was not observed prior to release. Partial dieback was not associated with any particular FOLR group. Poor vigor of the low and medium FOLR grades appeared to be responsible for mortality that occurred between the 5th and 7th year. The seedlings within a specific FOLR grouping were uniform in size and mortality did not appear to be related to their initial sizes.

Accounting for seedling response post release by FOLR grouping was difficult. This is because seedling damage did not appear to be related to their heights. Thus, when evaluating the shelterwood treatment, we combined all individuals, regardless of initial FOLR groupings for comparing initial seedling heights with 7th year pre-release and 3 years post harvest (table 2). All initial mean heights met or exceeded stem morphological conditions considered acceptable for advanced regeneration of NRO. Oak regeneration is not satisfactory in this shelterwood with a maximum growth response of only 60 centimeter

Table 2—Initial, seventh year pre-harvest and eleventh year post-harvest mean heights and stem condition of northern red oak 3 years after shelterwood removal

	Before Shelterwood Removal		Post-harvest
2000 Stem condition	Initial Ht 1990 (cm)	7th Year Ht 1997 (cm)	11th Year Ht 2000 (cm)
Dead	95	140	0
Undamaged	101	141	163
Top 1/3 stem damaged	105	139	115
Top 2/3 stem damaged	117	160	96
Stem missing - sprouting from root collar	108	145	84
Stem flat on ground - sprouting along length	141	193	103

for 11 years (table 2). These results are typical for NRO responses in a shelterwood and have contributed to artificial regeneration being a questionable recommendation.

Trees excavated from the shelterwood after year 5 showed that FOLR numbers had declined for each seedling examined. This was relatively unexpected. Underplanting or shelterwood regeneration assumptions are that the released seedlings or newly developed seedlings will develop a vigorous root system and be competitive when the stand is harvested even if top is damaged during canopy removal. It has been reported that unfavorable edaphic or environmental conditions such as low light intensity can result in a reduction in FOLR numbers and vigor with a preferential carbon allocation to the taproots at the expense of the lateral roots in NRO and white oak seedlings (Kormanik and others 1995, Sung and others 1998) as well as in loblolly pine trees (Sung and others 1996). Eventually, however, taproots begin to deteriorate and seedling mortality occurs. This unfavorable root deterioration was not observed on the individuals excavated from the clearcut area where photosynthetic active radiation was at least 1500 micromole/meter^2/second. The shelterwood had photosynthetic active radiation levels of less than 5 percent of this.

The pre-release seventh year mean height increases since shelterwood establishment for the high, medium, and low FOLR groups were 50, 40, and 30 centimeter, respectively (figure 2). The tallest seedlings were 280, 200, and 170 centimeter for each FOLR group, respectively. Three years post harvest showed the mean heights remained essentially the same or were reduced somewhat following shelterwood removal (figure 2). All seedlings under the shelterwood developed poorly and pre-release data indicate few seedlings were large enough to obtain DBH measurements. Three years post release DBH development was still unsatisfactory mirroring the lack of RCD growth for the first 5 years under the shelterwood (figure 3).

Clearcut

At age 5 when potential future dominant individuals were selected, the tallest individual from the high, medium, and low FOLR groupings were respectively 5.1, 4.6 and 2.4 meter. However at age seven and before release, only the selected individuals from the high and medium groups were still free-to-grow. Post release response was apparent with 6 to 8 meter trees being present by age 11 with mean heights of the high and medium FOLR grouping being 3.5 and 2.7 meter, respectively (figure 2). Post release DBH development, was impressive with almost a doubling in DBH over a 3 year period (figure 3). This response was in spite of the leaf maggot infestation during year one post release that seriously reduced leaf photosynthesis potential for that entire growing season.

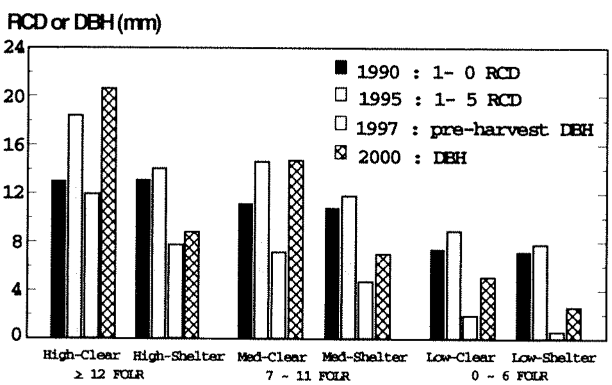


Figure 2–Height of northern red oak planted on clearcut site and under shelterwood.

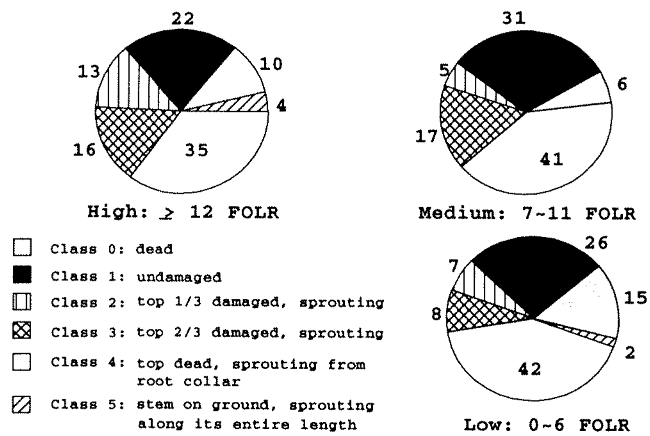


Figure 3–Diameter of northern red oak planted on clearcut site and under shelterwood.

Large differences were observed in all growth parameters among FOLR groups in the clearcut but survival as explained earlier was not related directly to FOLR groups or seedling sizes. All seedlings remained free-to-grow during their first year since stumps had not yet sprouted nor had the newly germinating competitors attained a competitive position. However, between years two and five, rapid growth of stump sprouts and development of new seedlings competitors resulted in steadily increasing competition. When the first re-measurements were made at year five, the artificially regenerated NRO seedlings were competing against 126,800 stems/hectare from 14 different deciduous hardwood species. However, the most severe competition was from stump sprouts of yellow poplar, red maple, and Carolina silverbell which each year became more critical as their rapidly developing crowns began to complete with the slower developing NRO crowns.

The competing vegetation was not re-inventoried prior to release but stem numbers did not appear to have declined much because of the absence of obvious mortality. At pre-release, age 7, competition of the dominant canopy level was primarily due to the rapidly growing stump sprouts. However, NRO individuals were still competing successfully against naturally regenerated seedling. These established small naturally regenerated seedlings did not respond immediately to clearcut and few of them produced more than 3 to 5 leaves either the first or second year following the clearcut and thus, as reported by others, did not benefit from it (Pope 1993).

Many of the large artificially regenerated seedlings remained free-to-grow or codominant until about the end of the 4th growing season unless they were planted immediately adjacent to stump sprouts. These large NRO seedlings that were at least 1 meter tall had a clear early advantage over competitors that began at ground level. During this first year the artificially regenerated oak benefitted from full sunlight and developed a root system required to compete with a wide range of competitors as the new stand developed.

Release at age 7 not only stimulated the NRO seedlings dramatically (figures 2, 3), but also had a comparable effect on the stump sprouts outside the 0.9 meter radius around the released individuals. Three years post release resulted in yellow poplar stump sprouts adjacent to the released individuals developing DBH's of 15 to 20 centimeter and obtaining heights of 6 to 10 meter. They are now, at age 11, clearly invading the NRO growing space. It is encouraging, however, that the potential dominant individuals selected at age 5, are still maintaining crown position with competitors of seedling origin but would benefit from further release to permit broader crown expansion.

CONCLUSION

After 11 years evidence is substantial that large NRO seedlings with adequate FOLR numbers are competitive and can be established on high quality mesic sites. Treatment of stumps prior to enrichment plantings or establishing mast producing areas will be required because even the largest and most competitive seedling cannot compete against stump sprouts on these excellent sites. In the absence of stump sprouts following an effective clearcut and site preparation, large NRO seedlings may not need release until ages 5 to 7 and, perhaps again at 10 to 12 years. Potential dominant trees that were selected at age 5, retained that status after release at age 7. Individual NRO oak seedlings with fewer than 4 FOLR were generally not competitive. Locust borer damage on them could not be ascertained from this study.

As of age 11, response from the shelterwood has not been satisfactory regardless of FOLR grouping. Neither height growth nor stem caliper have been acceptable compared to the clearcut response. The shelterwood site will be remeasured at 5 years post release. This will afford a comparison to the original clearcut at age 5 to determine to what degree the potential competition has developed since the shelterwood was removed. It appears unlikely, based on the ecology at these mesic sites, that any shelterwood type could be depended upon to establish NRO regeneration: too little sunlight and NRO will not grow or sufficient sunlight and the competitors will multiple rapidly. The question of what is too much overhead cover remains an open question and how to regulate competition to maintain NRO in a competitive position is difficult to ascertain. Certainly full sunlight is the best choice for NRO regeneration.

Neither shelterwood nor clearcutting in conjunction with the best most competitive NRO seedlings available will likely succeed in establishing this species on the desirable mesic sites without both mechanical and chemical control of competitors applied in a timely and effective schedule. Continued restriction in harvesting and chemical control of competitors may indeed contribute to NRO attaining the status of "California Condor" in the eastern deciduous forests as some have predicted (Kellison 1993).

LITERATURE CITED

Johnson, P.S. 1993. Sources of oak reproduction. In Loftis, D.L.; McGee, C.E. ed. Symposium Proceedings. Oak regeneration: serious problems, practical recommendations. 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 112-131.

Kellison, R.C. 1993. Oak regeneration-where do we go from here? In Loftis, D.L.; McGee, C.E. ed. Symposium Proceedings. Oak regeneration: serious problems, practical recommendations. 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment: 308-315.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. 1994. Toward a single nursery protocol for oak seedlings. In Proceedings: 22nd southern forest tree improvement conference, 1993 June 14-17, Atlanta, GA:114-123.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. (and others) 1995. Effect of apical meristem clipping on carbon allocation and morphological development of white oak seedlings. In: Edwards, M. B., ed. Proceedings of the eighth biennial southern silvicultural research conference; 1994 November 1-3; Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 332-337.

Loftis, D.L. 1983. Regenerating Southern Appalachian mixed hardwood stands with the shelterwood method. Southern Journal of Applied Forestry 7: 212-217.

McGee, C.E.; Loftis, D.L. 1986. Planted oaks perform poorly in North Carolina and Tennessee. Northern Journal of Applied Forestry 3: 114-116.

Pope, P.E. 1993. A historical perspective of planting and seeding oaks: progress, problems, and status. In Loftis, D.L.; McGee, C.E., ed. Symposium Proceedings. Oak regeneration: serious problems, practical recommendations. 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 224-240.

Sanders, I.L. 1971. Height growth of new oak sprouts depends on size of advanced reproduction. Journal of Forestry 69:809-811.

Sanders, I.L. 1972. Size of advanced reproduction: Key to growth following harvest cutting. U.S. Department of Agriculture, Forest Service, Res. Pap. NC-79. U.S. 6 p.

Sanders, I.L.; Graney, D.L. 1993. Regenerating oaks in the Central states. In Loftis, D.L.; McGee, C.E., ed. Symposium Proceedings. Oak regeneration: serious problems, practical recommendations. 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment:174-183.

Sung, S.S.; Kormanik; P.P; Black, C.C. 1996. Temporal and spatial aspects of root and stem sucrose metabolism in loblolly pine trees. Tree Physiology 16:1003-1008.

Sung, S.S.; Kormanik, P.P.; Zarnoch, S.J. 1998. Photosynthesis and biomass allocation in oak seedlings grown under shade. In Waldrop, T.A., ed. Proceedings of the ninth biennial southern silvicultural research conference. 1997 February 25-27; Clemson, S.C. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 227-233.

FIRST-YEAR SURVIVAL AND GROWTH OF BAREROOT AND CONTAINER WATER OAK AND WILLOW OAK SEEDLINGS GROWN AT DIFFERENT LEVELS OF MINERAL NUTRITION

Hans Williams and Matthew Stroupe[1]

Abstract—Bareroot and container water oak (*Quercus* nigra) and willow oak (*Quercus* phellos) seedlings were treated with 3 different levels of nitrogen (N) mineral fertilizer applied during the growing season in the nursery. Comparisons were made between species, N treatments, and stock-types for seedling morphology, first-year survival and height growth, and seedling water relations. Water oak seedlings were shorter, heavier, and more first-order lateral roots than the willow oak seedlings. The N fertilizer treatments did not have a statistically significant effect on seedling morphology. Bareroot seedlings were taller, had greater root-collar diameters, and were heavier than the container seedlings. The seedlings were hand-planted on an old pasture site located near Nacogdoches, TX. First-year survival was about 80 percent regardless of species, N treatment, or stock-type. Bareroot seedlings had less first-year height growth than container seedlings. Container seedlings fertilized at the highest N rate had greater stomatal conductance and transpiration rates early in the growing season than the container seedlings fertilized at the lowest rate.

INTRODUCTION

The reforestation of frequently flooded agricultural land with bottomland hardwood species has become an important activity in the Southeastern U.S. Federal programs like the Wetland Reserve Program (WRP) have promoted the reforestation efforts by providing financial support to landowners(Shepard 1995). A significant portion of the reforestation has occurred in the Lower Mississippi Alluvial Valley (LMAV). Compliance with the Clean Water Act and plantings initiated by organizations such as the The Nature Conservancy and Ducks Unlimited also contribute to the bottomland hardwood reforestation activity. Survival and early growth is often poor for these plantings because of frequent, long-term, flooding and herbaceous and woody plant competition. As a result, research continues to study ways to improve bottomland hardwood reforestation success (Allen 1990).

At locations where flooding is minimal, research results indicate that establishment with bareroot seedlings can be successful. Allen (1990) observed adequate bottomland hardwood oak stocking for five planted seedling stands (266 trees/ac.) and five direct seeded stands (293 trees/ac.) about 6 years after establishment. Miwa (1995) observed first-year seedling survival greater than 70 percent for four bottomland hardwood species planted on hydric and non-hydric soils which no longer experience significant flooding. Five years after planting, seedling survival was still greater than 60 percent (Ozalp and others 1998). Stanturf and Kennedy (1996) observed survival exceeding 60 percent after 5 years for cherrybark oak (*Quercus pagoda)* seedlings planted in a floodplain clearcut.

The use of container-grown hardwood seedlings instead of bareroot seedlings may be a potential option for the reforestation of flood-prone sites. White and others(1970) presented the possible advantages of using container hardwood planting stock. Advantages that may be especially important to a wetland reforestation planner are the ability to extend the planting season and the higher survival usually observed on adverse sites. For example, container seedlings could be planted after the floodwaters recede in early summer. Bareroot seedlings, typically lifted from the nursery during the winter, must spend an extended period of time in cold storage prior to planting. Since hardwood seedlings are sometimes packed in bundles or bags that cannot be completely sealed, there is a risk of seedling desiccation during unplanned, long-term cold storage.

In this study, bareroot and container water oak and willow oak seedlings were treated at 3 different levels of nitrogen. The objectives of the research included studying the early survival and growth between bareroot and container seedlings. Also, the effects of altering N rates in the nursery were observed for seedling morphology and field survival and growth.

METHODS

The container seedlings were grown under a shadehouse located at Stephen F. Austin State University, Nacogdoches, TX. The shadehouse was covered with a fabric that allowed 50 percent of the incident light to reach the seedlings. Water oak and willow oak seed were purchased from a regional vendor. The seed were sown in March, 1996, in 164 cm^3 plastic cone container filled with a

[1]Associate Professor, Arthur Temple College of Forestry, Stephen F. Austin State University, Nacogdoches, TX; Forester; Barksdale Air Force Base, U.S. Department of Defense, Shreveport, LA., respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

peat-perlite-vermiculite medium. Seedlings were grown at a density of 264 seedlings /m^2. The seedlings were irrigated as needed to prevent plant water stress.

The bareroot seedlings were grown at the Texas Forest Service Indian Mound Nursery, Alto, TX. The water oak and willow seed were collected from an orchard located near the nursery. The seed were sown in nursery beds in the Fall, 1995. During the 1996 growing season, the seedlings were irrigated with about 2 cm of water per week. The seedlings were top-pruned to a height of about 51 cm in July and August, 1996. Seedbed density at the end of the growing season was 86 seedlings/m^2 for water oak and 118 seedlings/m^2 for willow oak.

The fertilizer treatment involved increasing the nitrogen rate 2-times (2X) and 3-times (3X) the operational rate (1X). For the container seedings, a 15-30-15 (N-P_2O_5-K_2O) water soluble fertilizer was used. The 1X treatment, the operational rate, was equivalent to applying 34 kg N ha/yr. The fertilizer was applied over 10 applications during the 1996 growing season. The bareroot seedlings were fertilized with liquid ammonium nitrate (32-0-0). The 1X rate was equivalent to applying 18 kg N ha/yr. The fertilizer was applied over 5 applications during the 1996 growing season.

Prior to planting, ten seedlings were randomly sampled from each replication, stock-type, species and fertilizer treatment combination for biomass measurements. Each seedling was measured for height, root-collar diameter (RCD), number of first-order lateral roots (FOLR) greater than 1 mm in diameter, shoot oven-dry weight, and root oven-dry weight. The seedlings were hand-planted, using planting shovels, in January,1997. The planting site is at the Alazan Bayou Wildlife Management Area located about 11 km south of Nacogdoches, TX. The site was former pasture with soils from the Woden series(Typic Paleudalfs)and contains inclusions of soil from the Mantachie series (Aeric Fluvaquent) series.

Measurements after planting include first-year height growth and survival. Also, during the growing season following planting, leaf water potential, stomatal conductance, and transpiration was measured for container water oak and willow oak seedlings treated at the 1X and 3X N rates in late-June and late-August. Leaf water potential was measured with a plant pressure chamber. Stomatal conductance and transpiration was measured using a steady-state porometer. The measurements were conducted at mid-day (about 1:00 to 2:00 pm). The leaf water relation measurements were conducted on four seedlings from each replication, species, and N-rate treatment combination.

The study was designed as a randomized complete block split plot with 3 replications. The whole plots were the stock-types, the subplots were the species, and the sub-subplots were the N fertilizer rates. Differences between main effects and their interactions for the dependent variables measured are discussed as statistically significant at the 5 percent probability level.

Table 1—Mean morphological characteristics prior to planting of bareroot and container water oak and willow oak seedlings treated with three levels of nitrogen fertilizer

Treatment	Stem Height (cm)	Root-Collar Diameter (mm)	First-Order Lateral Roots (no.)	Shoot Weight (g)	Root Weight (g)
Stock-type					
Bareroot	65**	8.9*	10*	13.5*	14.3*
Container	38	5.5	5	1.8	3.0
Species					
WaterOak	50*	7.3	9*	8.7*	10.0*
Willow Oak	53	7.1	7	6.6	7.0
Nitrogen Rate[b]					
1X	49	7.1	8	7.6	9.0
2X	53	7.1	8	7.5	8.0
3X	52	7.4	8	7.8	9.0

[a] Means within a treatment followed by an asterisk are statistically different at the 5 percent probability level.
[b] The 1X N rate was 18 kg N ha/yr and 34 kg N ha/yr for bareroot seedlings and container seedlings, respectively.

RESULTS

Bareroot seedlings were taller, had larger RCD, were heavier and had greater number of FOLR than the container seedlings (table 1). Water oak seedlings were shorter than the willow oak seedlings, but had a greater number of FOLR. a. Means within a treatment followed by an asterisk are statistically different at the 5 percent probability level b. The 1X N rate was 18 kg N ha/yr and 34 kg N ha/yr for bareroot seedlings andcontainer seedlings, respectively Water oak seedlings were heavier than the willow oak seedlings. The N fertilizer treatment did not have a statistically significant effect on seedling morphology measured prior to planting. The statistically significant interactions between species and stock-types for seedling morphology were relatively small. Bareroot water oak seedlings were shorter than bareroot willow oak seedlings. Container water oak seedlings were taller than container willow oak seedlings. Bareroot seedlings fertilized at the higher N rates were shorter than the bareroot seedlings fertilized at the lowest N rate. Container seedlings were taller when fertilized at the higher N rates. Bareroot water oak seedlings had larger RCD than the bareroot willow oak seedlings, but the container seedlings of both species, had a similar RCD. Bareroot water oak seedlings had heavier stems than the bareroot willow oak seedlings. The container water oak seedlings had lighter stems than the container willow oak seedlings. Bareroot water oak seedlings had heavier roots than the bareroot willow oak seedlings. The container seedlings of both species had similar root weights. Bareroot willow oak seedlings had a

Table 2—Mean first-year survival, height growth and percent stem dieback for bareroot and container water oak and willow oak seedings treated in the nursery with 3 levels of nitrogen fertilizer

Treatment	Survival (Percent)	Stem Growth (cm)	Dieback (Percent)
Stock-type			
Bareroot	81	8*[a]	6.8
Container	83	27	1.1
Species			
WaterOak	81	15*	4.2
Willow Oak	82	20	3.7
Nitrogen Rate[b]			
1X	85	17	3.6
2X	81	19	4.1
3x	79	17	4.2

[a] Means within a treatment followed by an asterisk arestatistically different at the 5 percent probability level.
[b] The 1X N rate was 18 kg N ha/yr and 34 kg N ha/yr for bareroot seedlings and container seedlings,respectively.

Table 3—Mean mid-day stomatal conductance (g_w), transpiration (E), and leaf water potential (Y),for container water oak and willow oak seedlings treated in the nursery with 2 levels of nitrogen fertilizer. Seedlings measured during growing season after planting

Treatment	g_w (mmoles $m^{-2} s^{-1}$)	E (mmoles $m^{-2} s^{-1}$)	Y (MPa)
	June 23-27, 1997		
Species			
Water Oak	343.0	7.84	-1.6
Willow Oak	264.2	6.2	-1.7
Nitrogen Rate			
1 X	258.9*[a]	5.97*	-1.6
3 X	343.7	8.07	-1.7
	August 25-28, 1997		
Species			
WaterOak	434.5	12.20	-1.8
WillowOak	431.4	12.41	-2.2
Nitrogen Rate[b]			
1 X	402.6	11.73	-2.1
3 X	463.3	12.89	-2.0

[a] For each sample period, means within a treatmentfollowed by an asterisk are statistically different atthe 5 percent probability level.
[b] The 1X N rate was 18 kg N ha/yr and 34 kgN ha/yr bareroot seedlings and container seedlings, respectively.

lower number of FOLR than the bareroot water oak seedlings. Container seedlings of both species have similar numbers of FOLR. Water oak seedlings fertilized at the higher N rates had greater numbers of FOLR than water oaks fertilized at the lowest N rate. Willow oak seedlings fertilized at the lowest N rate had higher numbers of FOLR than the willow oak seedlings fertilized with the higher N rates.

First-year survival after planting was about 80 percent or greater regardless of stock-type, species or N-rate treatments (table 2). Container seedlings had greater first-year shoot growth than the bareroot seedlings. Willow oak seedlings had greater shoot growth than the water oak seedlings. The N fertilizer treatment did not affect first-year survival and shoot growth. Bareroot willow oak seedlings had greater amounts of shoot growth than the bareroot water oak seedlings. The container seedlings of both species had similar amounts of shoot growth. Bareroot seedlings fertilized at the higher N rates had greater shoot growth than the bareroot seedlings fertilized at the lowest N rate. First-year height growth was less for container seedlings fertilized at the highest N rates.

The difference in mid-day stomatal conductance, transpiration, and leaf water potential between container water oak and willow oak seedlings was not statistically significant when measured in late-June and late-August following planting (table 3). The container seedlings fertilized at the highest N rate had statistically greater rates of stomatal conductance and transpiration when measured in late-June. Differences between N-rate treatments were not statistically significant when measured in late-August.

CONCLUSIONS

The careful seedling handling and planting and the adequate growing conditions may partially explain the good first-year survival for all treatment combinations. While the seedlings were planted in a location with significant herbaceous and woody plant competition, the 1997 growing season was characterized by above average rainfall. In August alone, over 30 cm of rain occurred in Nacogdoches, TX. Bareroot hardwood seedlings require careful handling, especially to protect the root systems. However, when the right species are matched to the site and proper handling and planting procedures are followed, good early establishment of bareroot seedlings should be expected (Kennedy 1993). The greater first-year height growth observed for the container seedlings may be a response to the reduced handling and planting stress when compared to bareroot seedlings (White and others 1970). Williams and Craft (1998) observed similar first-year results for bareroot and container Nuttall oak (*Quercus texana*) seedlings planted on a hydric soil in the LMAV.

REFERENCES

Allen, J. A. 1990. Establishment of bottomland oak plantations on the Yazoo National Wildlife Refuge Complex. Southern Journal of Applied Forestry 14(4): 206-210.

Kennedy, Jr. H. E. 1993. Artificial regeneration of bottomland oaks. In: Loftis, D.; McGee, C. E., eds. Oak regeneration: Serious problems, practical recommendations. Symposium Proceedings; 1992 September 8-10; Knoxville, TN Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 241-249.

Miwa, M. 1995. Reestablishment of bottomland oak species in lower Mississippi Valley alluvial soils. Tech. Rep. WRP-RE-14, Vicksburg, MS, U.S. Army Engineers Waterways Experiment Station.

Olzap, M.; Schoenholtz, S. H.; Hodges, J. D.; Miwa, M. 1998. Influence of soil series and planting methods on fifth-year survival and growth of bottomland oak reestablishment in a farmed wetland. In: Proceedings of the 9th Biennial Southern Silvicultural Research Conference; 1997 February 25-27; Clemson, SC. Gen. Tech. Rep. SRS-20, Asheville, NC: U.S. Department of Agriculture. Forest Service, Southern Research Station: 277-280.

Shepard, J. P. 1995. Reforesting marginal agricultural land. Forest Farmer 54: 7-19.

Stanturf, J. A.; Kennedy, H.E., Jr. 1996. Survival and growth of planted and direct seeded cherrybark oak in South Carolina. Southern Journal of Applied Forestry 20(4): 194-196.

White, D. P.; Schneider, G.; Lemmien, W. 1970. Hardwood plantation establishment using container grown stock. Tree Planters' Notes 21(2): 20-25.

Williams, H. M.; Craft, M. N. 1998. First-year survival and growth of bareroot, container, and direct-seeded Nuttall oak planted on flood-prone agricultural fields. In: Proceedings of the ninth biennial southern silvicultural research conference; 1997 February 25-27; Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U. S. Department of Agriculture, Forest Service, Southern Research Station: 300-303.

CHERRYBARK OAKS FROM PERFORATED CONTAINERS PLANTED AS BAREROOTS WITH OPEN-GROWN OAK BAREROOTS

Kirk D. Howell[1]

Abstract—Large Cherrybark oak (Q. *pagoda* Raf.) grown for two years (1997 and 1998) were hoedad planted in bottomlands near Columbia, South Carolina. Successful oak plantations exist from planted bareroot cherrybark oak seedlings with heights below 50 centimeters, but costly efforts were often employed to ensure success. To overcome competing vegetation, seedlings greater than 1 meter are essential, but the roots of large oak seedlings present obstacles to planting. The one-liter, perforated container was designed to promote fine, feeder roots to penetrate outside of the container, and to restrict woody root formation at the soil-container interface. After two nursery growing seasons, there were no significant differences in survival, but yield favored conventional bareroot seedlings of 100 per square meter. Field survival of containerized seedlings after two years were significantly greater than bareroot seedlings, compensating for the higher cost of containerized seedlings. Seedlings from containerized stock of 100 per square meter also showed the greatest significant yield by year two.

INTRODUCTION

With increased demand for high quality oak products and potential legislation to restrict clearing of natural forests (Kellison 1993), it may not be enough to simply mimic nature = s processes in artificial oak regeneration, but to improve on them. Producing higher yield on less land with fewer starting costs is a prudent goal for the land manager, regardless of whether the land is publicly or privately owned.

Much research has been conducted to show the importance of oak seedlings having a bulky root system, and hence several first-order lateral roots (FOLR) (Ruehle and Kormanik 1986), which give rise to second-order laterals roots, and to fine, fibrous roots. For greatest stem size potential, it is preferable to have greater than 8 FOLR along the distal tap (Kormanik et al. 1994), with FOLR diameters above 1mm (Thompson and Schultz 1994). Otherwise, seedlings are labeled by some researchers as Agenetic trash@. Unfortunately, after the planting process, root pruning (i.e., tailoring the seedling's root system to fit the planting hole) compromises many of these gains realized in the nursery.

Oak plantation success (i.e., an efficient operation) hinges on 1) high yield and 2) low initial costs. Poor cost efficiency involves one or both factors being deficient. In a study established in 1994 (Howell and Harrington 2002), undersized cherrybark oak (Q. *pagoda* Raf.) seedlings, grown three months in a greenhouse, survived and grew quite well, but not without the aid of high-priced fencing to protect them from browse. Moving away from protective shelters, a preferable option might be found with larger seedlings planted in open-field conditions.

The optimum size that would ensure plantation success at the lowest possible cost is debatable.
Ground-line diameter may be the single most useful morphological measure of seedling quality (Johnson and Cline 1991) — ensuring field survival and promoting rapid growth (Mexal and South 1991); moreover, diameter is a good indicator of root mass (Coutts 1987). A competitive oak seedling should have a ground-line diameter above 10 millimeters (Pope 1993). Moreover, stem height above 1.5 meters is considered adequate to overcome competing vegetation and deer browse (Hannah 1987).

The perforated container (U.S. #6,173.531), patented in January 2001, is designed to restrict and train root growth. The patented hole perforations are to be substantially 1.5 millimeters, the midpoint between woody and feeder-root range, > 2 and < 1 millimeters, respectively (Lyford 1980). Upon inserting these containers into the ground, fine and fibrous root growth is encouraged, and the taproot should extend to the bottom of the container, where it follows the water pathway out of the container into the surrounding seedbed. With these large containers, the soil can be removed at the nursery for economic reasons, and thus bareroot seedling transport and planting are facilitated, hence the term Acontainerized-bareroot@. Therefore, the objectives of plantability and ease of transport should be satisfied, but what is more important is that this method may offer a more positive yield forecast.

[1]Regeneration Forester, Ph.D. candidate, Department of Forest Resources, Clemson University, Clemson, SC 29634-1003

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

MATERIALS AND METHODS

Cherrybark oak seeds were sown (February 1997) as conventional bareroot or inside perforated containers in a partially shaded nursery in Auburn, GA. Two densities of 64 and 100 seeds per square meter were also tested. A third factor of perforation size (1 versus 1.5 millimeter holes) was tested for containers, and for conventional bareroot, the factor of trimming versus nontrimming was tested at planting. Thus, a randomized block design was employed with eight treatments across three blocks in the nursery, and 20 seeds sown per treatment per block. A completely randomized design was installed where nine stems were selected from each treatment, and replications were planted in designated positions in the field.

Due to the shaded conditions, portable greenhouses and lighting were used to provide a 2-month head start on the 1997 season. Seedlings emerged by early March, and by April 1, 1997, all growth devices were removed. Another aid to promote high-density growth was with lateral branch pruning. This operation was performed for six months (late April-late September) for two years. Seedlings were fertilized with (20N-20P-20K) daily during the active growing season. Seedlings were not undercut, and after lifting, were immediately transported to the planting site. At planting, trimming was performed on designated bareroot seedlings and all seedlings were planted at a 3.66 by 3.66-meter spacing.

Diameter, height, and survival are yield factors expressed in the equation: $Y_t = Avg(B*r_t^2*h_t)/2*S_t$; where at year t: Y_t = yield (cubic decimeters), r_t = radius (decimeters), h_t = height (decimeters), and S_t = percent survival. Nursery yield, two years from sowing (November 1998), was expressed in terms of stems per 1000. Plantation yield, two years from planting (December 2000), was expressed in terms of 750 stems per hectare.

Our research was not empirical, so cost information was adopted from a firm of undisclosed identity. The nursery involved 20 hectare with a workable area of 7,500 square meters per hectare (25 percent non-workable roads and buffer areas). With about 67 percent germination in our study, there was an effective production of 6.4 and 10 million stems from densities of 64 and 100 stems per square meter, respectively. All costs were influenced by capacity, and were thus included in pricing, whether fixed or variable. Salaries, land, dues, insurance, etc. are some items to be included which did not vary with treatment. Other costs included were the purchase and handling of containers, portable greenhouses, and labor required to package, store, and transport seedlings. When pricing, 30 percent profit was added. Thus, the price from the nursery became the seedling cost for each treatment in the field. Seedling price and planting costs were also variable in this study. Land and site preparation costs were not included in this paper. Costs were compounded with time (t) as follows: C_t = EC * $(1+i)^t$; where: C_t = total cost ($); EC = the sum of all costs ($); i = interest (8 percent).

Yield to cost ratios (E_c) provide cost efficiency indices. The equation is given as: $E_c = C_t/Y_t$; where: E_c = cost efficiency ($ per cubic decimeters), C_t = total cost ($ per 1000 or $ per hectare), and Y_t = yield in terms of yield (cubic decimeters per 1000 or per hectare).

RESULTS AND DISCUSSION

In the nursery, we realized near 65 percent representation (emergence and survival), due to poor germination, and there with no significant differences (" 0.05) among treatments. Thus, effective density was less than that which was sown. After two years in the field (table 1), containerized bareroot had significant survival (about 78 percent) over conventional bareroot (about 49 percent). Nursery diameter, height, and yield favored conventional bareroot of density 100, and year-2 field diameter, height, and yield favored containerized-bareroot of density 100. As to why density 100 seedlings were larger than those of density 64 may be partly explained by the effective lower density after germination. However, since both treatment densities were reduced equally, the lowest density (64 seedlings per square meter) should have remained low and should have still supported the larger stems. Lateral branch pruning, which encourages mutual training, may have also had some impact on these results. Root alteration (Alt) showed no significant impact on yield or cost with containerized bareroot. However, the conventional bareroot, trimmed, 64 treatment was significantly greater than the rest in yield by year two.

Fixed costs (FC) ranged from 50 to 55 percent of the total costs of producing conventional bareroots. However, with containerization fixed costs ranged from 39 to 45 percent of the total, because about $30 per 1000 was needed to purchase containers (C), and an additional $55 per 1000 to embed and hand-sow the containers (SC). Mechanization of sowing conventional bareroot with two workers ($20 per hour) and a tractor drove sowing costs (SC) down to about 48 cents per 1000, plus or minus 5 percent for differences in density. Laborers involved in hand sowing, and other fieldwork, earn $10 per hour. If embedding containers could be mechanized, the higher wage and initial investments in machinery would over the long run lower the cost of the container-sowing operation. On the other hand, a $7,000 savings from not using the tractor when hand-sowing containers resulted in a minimal adjustment of $1 to $2 per 1000 (shown with FC). Some could argue that this justifies hand sowing using cheap labor.

Lateral branch pruning (table 2) was a cost factor unaffected by density ($62 per 1000), but the greatest cost benefit was realized by the fostering of increased basal diameter growth at the higher density. Lateral branch pruning (BP) also affected transport and packaging (TPK). Weight of a load to equal 13,620 grams (30 pounds) was utilized to determine the cost of transport and packaging. Since soil was removed from the containers at the nursery, and transport and packaging dealt with bareroot only, then the costs involved in transport was virtually the same for each treatment ($3.8 to $4.5 per 1000).

Table 1—Percent survival (Srv), diameter (Dia: mm), height (Hgt: cm), yield (Yld: cubic decimeters per 1000 for the nursery or per hectare in the field), and cost efficiency (Eff: dollars per cubic decimeter) at year-2 nursery (N), year-2 field (2), transport and planting costs (TP(0): dollars per hectare), and year-2 field cost (Cst(2): dollars per hectare) for each treatment of root form (containerized bareroot (container) and conventional bareroot (bareroot)), density (64 or 100 stems per square meter), and root alteration (Alt: 1.5 versus 1.0 millimeter holes in containers, or trimmed (Trim) versus not trimmed (Xtrm) applied to bareroots in the field). Reported significance (S) at ? = 0.05 level. Notation: no difference (N); Forms differ (F); Densities differ (D); and the form-density interaction (FD).

Form:	Container				Bareroot				
Dens:	*64*		*100*		*64*		*100*		
Alt:	1.0	1.5	1.0	1.5	Trim	Xtrm	Trim	Xtrm	-S-
Srv(N):	63	77	72	58	63	63	65	65	N
Srv(2):	73	92	73	73	51	40	48	55	F
Dia(N):	8.9	9.9	9.1	8.6	8.8	8.8	10.2	10.2	FD
Dia(2):	14.7	13.9	16.8	18.1	14.3	12.9	13.2	11.3	FD
Hgt(N):	101	116	112	112	105	105	124	124	FD
Hgt(2):	131	140	180	171	148	124	125	124	FD
Yld(N):	39	48	37	41	39	39	57	57	FD
Yld(2):	81	94	127	149	81	34	43	30	FD
Eff(N):	11.5	9.4	9.5	8.6	9.4	9.4	4.6	4.6	FD
Eff(2):	7.4	6.1	4.0	3.3	6.2	15.8	8.8	13.5	FD
TP(N):	115	89	122	108	98	139	89	123	
Cst(2):	599	576	506	493	502	538	377	406	

The variable costs were responsible for adding an approximate $100 to containerized treatment over the conventional bareroot treatment. All costs (variable and fixed) were affected by density, since recompense involves seedling quantities rather than seedling qualities. If products were priced according to aspects of quality, pricing would be in terms of dollars per weight or volume. The cost of nursery land ($6.4 and $4.2 per 1000 for densities of 64 and 100, respectively) was spread over 30 years, and was an insignificant charge as compared to the total cost of operations.

Table 2— An itemized cost list (dollars per 1000) involving fixed costs (FC) in the nursery (wages and salaries, operations, utilities, and anything which is not specified separately). Other variables include costs of: land (LC), sowing (SC), lifting (Lft), loading and packaging (TPK), containers (C), fertilization and supplies (F), small portable greenhouses and lighting (GL) and branch pruning (BP). Year-2 total cost is also listed (Cst).

Form:	Container		Bareroot		Form:	Container		Bareroot	
Dens:	-64-	-100-	-64-	-100-	Dens:	-64-	-100-	-64-	-100-
FC:	202	129	204	130	LC	6.4	4.2	6.4	4.2
SC:	53	58	.46	.50	Lft:	12.3	11.5	7.6	9.3
TPK:	3.8	4.5	4.2	3.8	C:	30	30	0	0
GL:	78	50	78	50	F:	3	2	3	2
Cst:	450	351	366	262	BP:	62	62	62	62

In the field (table 2), nursery cost with 30 percent profit made up the price of seedlings. Some states may require tax, but our state did not. Transport and planting (TP) involved an average charge of $150 per 1000 for large seedlings, as compared to a charge of $35 per 1000 for planting small, bareroot seedlings in the 1995 study (Howell and Harrington 2002). It is intuitive that larger seedlings will demand higher seedling prices and will require greater costs to plant them. Nevertheless, one worker planting 100 saplings per hour is well within the realm of a large-scale planting production rate. The cost of trimming bareroot seedlings was offset by the cost of carrying and planting untrimmed seedlings.

Cost efficient nursery benchmarks (table 1) were set by the conventional bareroot of density 100, because it possessed the lowest costs and also had the highest yield. The $4.6 per cubic decimeter of this study was about 47 times as low as the best treatment of the 1995 study ($215 per cubic decimeters). After two years in the field, the containerized bareroot of density 100 was optimum, where high yield overcame the relatively higher costs of production, and it was the low field survival that hurt the conventional bareroot. The $3.8 per cubic decimeter value of this study was about three times below that of the best treatment ($12.4 per cubic decimeters) of the 1995 study. There were some protection mechanisms utilized in the 1995 study, which were not needed in this study. The only other costs that could be realistically added to this study are the cost of land and site preparation. These marginal costs are minimal compared to the other costs, and would not greatly dilute the cost efficiency results of this study.

CONCLUSION

Containerization effectively restricts the root system to parameters conducive to high-volume planting, while preserving the fibrous root important for nutrient uptake in the field. The perforated container, used in this study, brought into one operation the benefits of both containerized and bareroot seedling culture, where perforated holes permitted only fine roots, those less than 2 millimeters in diameter (Hendrick and Pregitzer 1993), to penetrate the container interface into an extended rooting environment. While the general rule holds true for all forest species, this fine-woody root transition range between 1 and 2 millimeters (Lyford 1980) is subject to vary somewhat among species.

Neither cost inputs nor the yield output should be under emphasized in nursery or plantation levels. The long-term payoff (i.e., the return on the invested dollar) will depend upon: 1) stand yield, highlighting representation (emergence and survival); 2) individual stem yield, promoting high volume growth; and 3) the cost to produce, establish, and sustain the crop. Benchmarks in cost, yield, and their combined efficiency should be set, and will thus encourage the comparisons of operations over space (from region to region) and time (from generation to generation).

The cost benchmark at the nursery level was set in this study by the conventional bareroot treatment, of density 100, but the small, unfertilized treatment from the 1995 study held the best mark between the two studies (Howell and Harrington 2002). When looking at variable costs only, the same treatment from the 1995 study would logically remain lowest in seedling cost, and the cost of transport and planting. However, the cost of spending several thousand dollars per hectare to fence and protect undersized seedlings actually negates any perceived advantage in an applicable sense. The field cost efficiency benchmarks of this study were manifested; even though higher priced saplings were utilized, which involved greater storage, transport and establishment costs. However, the bonus is that they were planted in a clearcut area with a high-volume planting tool, and without the aid of expensive shelters or fences for protection.

While nursery yield was best for the conventional bareroot, density 100 treatment, after two years in the field, the containerized, density 100 treatment set a second-year benchmark in this study. Second-year nursery yield in our study was 20 times that of the best treatment from the 1995 study, because our seedlings had a morphological age perhaps closer to what would be classified as fifth-year growth under natural conditions. Five-year morphological sizes are required for saplings to have a fighting chance to survive in indigenous sites where pioneer conifers and hardwoods possess faster growth rates (Clatterbuck 1987), especially for upland oaks on upland sites (McGee 1975; Loftis 1983). The oak paradox seems to be epitomized more with northern red oak than it is with cherrybark oak.

The container, 100 treatment showed the best cost efficiency in our study, and now offers a milestone with which to engage future findings. Undoubtedly, the cost efficiency benchmark set in this study will soon be superceded by innovative measures, which reduce costs or increase performance. Some of these measures may be found in: 1) growing larger seedlings at higher densities; 2) increasing seedling representation through improvements in germination and survival methods; and 3) facilitating branch pruning and/or root initiation by way of chemical or hormonal application. Once oak plantation success can be guaranteed on clearcuts of high site quality, morphologically superior oaks may be interplanted with low-cost, 1-0 pines for training purposes. As of now, however, pines are viewed as major oak competitors.

REFERENCES

Coutts, M.P. 1987. Developmental processes in tree root systems. Canadian Journal of Forest Research. 17: 761-767.

Hannah, P.R. 1987. Regeneration methods for oaks. NJAF 4: 97-10.

Howell, K.D.; T.B. Harrington. 2002. Container size and fertilization affect nursery cost fifth-year field performance of cherrybark oak. [This proceedings].

Johnson, J. D.; M. L. Cline. 1991. Seedling quality of southern pines. p. 143-159 In;: Duryea, M. L. and Dougherty, P. M. (Eds). Forest Regeneration Manual. Kluwer Academic Publishers. Dordrecht/Boston.

Kellison, R.C. 1993. Oak regeneration B where do we go from here? In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: serious problems, practical recommendations: Symposium proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 308-315.

Lyford, W.H. 1980. Development of the root system of northern red oak (Quercus rubra L.). Harvard Forest Research Paper, No. 21.

Mexal, J. G.; D. B. South. 1991. Bareroot seedling culture. Chapter 6,. In:: Duryea, M. L. and Dougherty, P. M. (Eds). Forest Regeneration Manual. Kluwer Academic Publishers. Dordrecht/ Boston: 89-115.

Pope, P. E. 1993. A historical perspective of planting and seeding oaks: progress, problems, and status. In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: serious problems, practical recommendations: Symposium proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 224-240.

GROWTH AND DEVELOPMENT OF FIRST-YEAR NURSERY-GROWN WHITE OAK SEEDLINGS OF INDIVIDUAL MOTHER TREES

Shi-Jean S. Sung, Paul P. Kormanik, and Stanley J. Zarnoch[1]

Abstract—White oak (*Quercus alba* L.) acorns from individual mother trees at Arrowhead Seed Orchard (ASO, Milledgeville, GA), Beech Creek Seed Orchard (BSO, Murphy, NC), and Savannah River Site (SRS, Aiken,SC) were sown in December 1999 at Whitehall Experiment Forest Nursery (Athens, GA). All 6 mother trees from BSO were grafted. By early April, germination exceeded 80percent for all but six families. Five of these six families were from BSO. Seedlings that emerged after mid-April generally were much smaller in size than those emerging earlier. More than 60 percent of seedlings from each seed source group had fewer than mean first-order lateral root (FOLR) number. Buds for the first flushes started swelling near the end of April for most seedlings. Time span from current bud swelling to next bud swelling in most seedlings was approximately 33 days for all flushes. Regardless of seed sources, elongation of the third, fourth, and fifth flushes occurred mainly between 4 and 12 days post bud break (dpbb) with most active elongation occurring approximately 10 dpbb. About 89, 55, and 9 percent of ASO and SRS seedlings had three, four, and five flushes, respectively. Only 60, 15, and 2 percent of BSO seedlings had three, four, and five flushes. Seedlings with first flush length shorter than 5 centimeter generally had lower values in growth parameters including height, root collar diameter, flush number, and FOLR number. Based on germination rate and first flush length, it may be possible to assess progeny quality of given mother trees as early as mid-May. Progeny from grafted mother trees performed poorly in nursery as compared to progeny from other groups based on all parameters except for diameter.

INTRODUCTION

There have been two *Quercus* regeneration practices used to maintain a significant oak component in new stands following a harvest. One practice depends on obtaining advanced oak regeneration by shelterwood or selection harvesting the current stands. Although this may be successful on lower quality upland sites (Sanders 1971, Lortis 1983), it may not be successful on high quality mesic sites due to the presence of fast growing, competing woody species that will generally occupy the site once the final canopy is removed (Loftis 1990, Hodges and Gardiner 1993, Lorimer 1993). The other practice, artificial oak regeneration, involves planting high quality 1-0 nursery stocks on clearcut sites as advocated by Kormanik and others (1997,1998,2000). This practice takes only the top 50 percent of 1-0 oak seedlings grown under a specific hardwood nursery protocol developed by Kormanik and others (1995). Seedlings are graded by their height, root collar diameter (RCD), and number of first-order lateral roots (FOLR) that are greater than 1 mm in diameter. It has been proven with loblolly pine (Kormanik and others 1990) and various oak species including white oak (Kormanik and others 1997, 2000) that FOLR number is highly heritable and a good indicator of seedling quality in nursery and outplanted performance in field.

Here we investigated the growth and development of 1-0 white oak seedlings from different mother trees from different states. The primary interest was to identify and quantify any early indicator of seedling quality that might be used with progeny from future mother tree selections.

MATERIALS AND METHODS

Open pollinated white oak (*Quercus alba* L.) acorns from individual mother trees in Arrowhead Seed Orchard (ASO, Milledgeville, GA), Beech Creek Seed Orchard (BSO, Murphy, NC) and Savannah River Site forest stands (SRS, Aiken, SC) were sown at a density of 54 to 57 per meter^2 in December 1999 at Whitehall Experiment Forest Nursery (Athens, GA). Seedlings were grown using the oak nursery protocol of Kormanik and others (1994). There were 25, 6, and 15 half-sib families from ASO, BSO, and SRS, respectively. All 6 mother trees from BSO were grafted. Four ASO, six BSO, and 14 SRS families were planted in a randomized block design with two blocks each consisting of 130 acorns per family. The other families were planted in an identical manner but with only 65 acorns per family per block. Germination percent was assessed as shoot emergence on March 23 and April 5, 2000. Numbers of seedlings with swelling first flush bud that was at least 3 millimeter long or elongating first flush were recorded for

[1]Research Plant Physiologist; Principal Silviculturist, Institute of Tree Root Biology, Southern Research Station, USDA-Forest Service, Athens, GA 30602; Mathematical Statistician, Southern Research Station, USDA-Forest Service, Asheville, NC 28802, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Germination and flush development of all white oak seedlings from individual mother trees at Arrowhead Seed Orchard (ASO), Beech Creek Seed Orchard (BSO), and Savannah River Site forest stands (SRS)

	ASO[a]	BSO	SRS
Acorn FW[b] (g)	4.6±1.2	4.3±1.1	4.3±1.1
Mar 23 Germ (pct)	85±8.9	60±29.0	87±7.4
Apr 5 Germ (pct)	90±8.0	62±30.0	92±4.9
Apr 25 1st Fl[c] (pct)	28±10.9	20±10.5	18±12.5
May 29 2nd Fl (pct)	55±9.2	27±8.1	37±17.3

[a] In December 1999, acorns from 25 ASO, 6 BSO, and 15 SRS mother trees were sown.

[b] Mean acorn fresh weigh (± sd) were obtained by weighing the entire family before sowing.

[c] Seedlings with swelling flush bud or elongating flush were considered to have initial flush development.

each family on April 25. Seedlings with swelling second flush bud or elongating second flush were counted for all families on May 29. All seedlings were lifted in late January 2001. Height, root collar diameter (RCD), and FOLR number were recorded for all seedlings of each of the 12 ASO, 6 BSO, and 15 SRS families. Thirteen ASO families with 65 acorns per family per block were not evaluated for these growth parameters.

In mid-April, 2000 we established the "All Flush Development Sub-study" that intensively followed 10 ASO, five BSO, and five SRS families. These families were part of those assessed for height, RCD, and FOLR number at lifting. For families with 65 acorn per replication every fifth seedlings were tagged for observation. For those families with 130 acorns per replication, every tenth seedling was tagged. This resulted in 13 seedlings per replication in each of the 20 families. Thus, a total of 520 seedlings were assessed for flush development two to three times a week throughout the growing season. The date of bud break as determined by the first appearance of a flush leaf, flush length, and leaf length were recorded.

On June 12, the "Detailed Flush Development Sub-study" was initiated on an additional 144 seedlings with swelling third flush buds. These seedlings were labeled and followed daily for flush elongation and leaf expansion. Development of the fourth and fifth flushes were followed every other day. This sub-study consisted of 68 seedlings from 18 ASO families, 9 seedlings from five BSO families, and 67 seedlings from 13 SRS families. Flush length was modeled on an individual seedling basis with the logistic equation defined as:

$$FLUSH = \frac{a}{(1 + e^{b + c\,DAY})}$$

where FLUSH = flush length (cm), DAY = days post bud break, and a, b, c = parameters of the logistic function. Nonlinear regression was used to estimate the parameters using PROC NLIN (SAS Institute Inc. 1989). The instantaneous rate of flush growth at a given day was obtained by determining the slope of the specific logistic

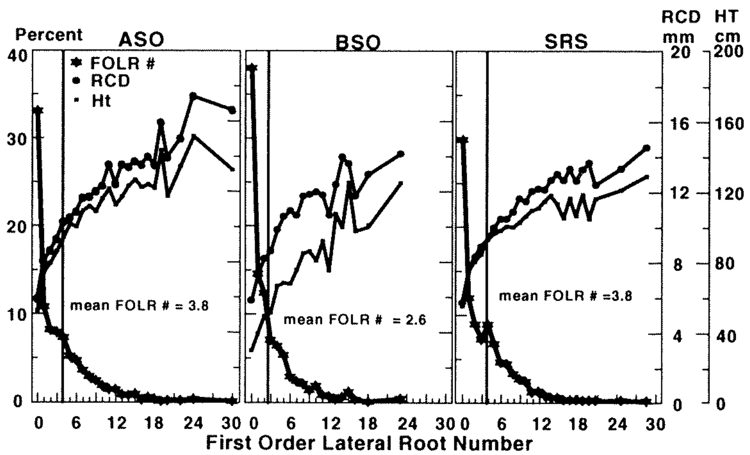


Figure 1—Frequency distribution of first-order lateral root (FOLR) number of 1-0 white oak seedlings with height and root collar diameter in each FOLR group. Acorns were from 12, 6, and 15 individual mother trees at Arrowhead Seed Orchard, Beech Creek Seed Orchard, and Savannah River Site forest stands, respectively.

Table 2—Comparisons between late emerging (after April 15, 2000) and normal emerging white oak seedlings from individual mother trees at Arrowhead Seed Orchard (ASO), Beech Creek Seed Orchard (BSO), and Savannah River Site forest stands (SRS)

Emergence time	Seed source	Germination Pct	Height cm	RCD mm	FOLR #
Normal[a]	ASO[b]	90.0	82±35.0	9.0±3.3	3.8±4.9
Late	ASO	0.5	52±28.0	5.6±2.2	1.4±2.2
Normal	BSO	72.0	49±28.3	8.1±2.7	2.7±3.6
Late	BSO	7.2	33±16.8	6.1±2.0	0.9±1.7
Normal	SRS	86.0	82±30.6	8.6±2.8	3.9±4.5
Late	SRS	2.4	48±29.8	5.1±2.5	1.0±2.3

[a] Seedlings germinated before April 15.

[b] Twelve ASO, 5 BSO, and 15 SRS families were assessed. Family NAWO-23 was not included because it only had 5 percent germination.

equation evaluated at that day. This was found by differentiation with respect to DAY, yielding

$$\text{SLOPE} = \frac{-a\,c\,e^{b+c\,\text{DAY}}}{(1+e^{b+c\,\text{Day}})^2}$$

and then substituting the appropriate day in this equation. The inflection point of the logistic function is where the instantaneous rate of flush growth reaches its maximum and begins to slow down. It is found by setting the second derivative equal to zero and solving for DAY, which yields Inflection Day = -b/a

RESULTS AND DISCUSSION

Main Study

Germination percentages were similar between ASO and SRS families with BSO having 25 percent less germination in March and April (table 1). By April 5, all but six families had more than 80 percent germination (data not shown). Families ASO-1, NAWO-23, SAWO-38, SAWO-28, NAWO-29, and NAWO-28 had 55, 5, 48, 73, 78, and 79 percent germination, respectively. The latter five families were from the Beech Creek Seed Orchard. No correlation existed between acorn weight and germination percent of individual families. Of these seed sources, more ASO seedlings started forming the first flush on April 25 and the second flush on May 29 than seedlings of the other two groups. More SRS seedlings had the second flush than BSO on May 29 (table 1).

When seedlings were pooled within each seed source and stratified based on their FOLR numbers, all three seed sources exhibited a reversed J distribution (figure 1). This relationship was also exhibited on an individual family basis (data not shown). Similar FOLR distributions have been reported for loblolly pine (Kormanik and others 1990) and various oak species including white oak (Kormanik and others 1997). Sixty-seven percent of ASO, 65 percent of SRS, and 70 percent of BSO seedlings had fewer than their respective mean FOLR number (figure 1). These values were comparable to the white oak results observed by Kormanik and others (1997). In the present study, 33, 30, and 38 percent of ASO, SRS, and BSO seedlings, respectively, had zero FOLR. Correlation coefficients between FOLR number and RCD were 0.75, 0.74, and 0.72 for ASO, BSO, and SRS seedlings. Correlation coefficients between FOLR number and height were 0.64, 0.69, and 0.55 for ASO, BSO, and SRS seedlings. Mean RCD were similar among three seed sources whereas BSO seedlings were 40 percent shorter than ASO or SRS seedlings (figure 1, table 2). There was a higher percent of late emerging BSO seedlings than SRS seedlings (table 2). Only a few ASO seedlings emerged after April 15. All the late emerging seedlings were smaller in size and had fewer FOLR than the normal seedlings (table 2).

Family SRS-596 had 85 percent germination on April 5 and about 35percent of these seedlings were albino, that is, their leaves had very low levels of chlorophyll. These seedlings eventually died. Furthermore, compared to the SRS group means, the green SRS-596 seedlings were smaller in size with 47 centimeter height and 6.8 millimeter RCD, but had 4.2 FOLR which is comparable to SRS group mean. Family KYWO-31 is the only grafted tree that had 91 percent germination in April. Still, mean height for this family was only 55 centimeter. Results from previous studies of acorns collected from grafted mother trees at BSO, including some of the same families in this study, showed low germination percent and short seedling size (Kormanik and others 1997). Reasons for poor germination and shorter stem for progenies from most grafted mother trees in Beech Creek Seed Orchard are unclear. This study indicated that based on germination percent, morphology, and growth parameters, ASO-1, SRS-596, and all BSO mother trees produce poor quality progeny.

Detailed Flush Development Sub-study

Figure 2 shows the daily growth of the third flush of an ASO-16 seedling with leaf length (long axis) expansion for the fourth leaf from the bottom of the flush. Most of the 144

Table 3—Growth and developmental parameter means (± sd) of 520 white oak seedlings from individual mother trees at Arrowhead Seed Orchard (ASO), Beech Creek Seed Orchard (BSO), and Savannah River Site forest stands (SRS)

	ASO	BSO	SRS
	General Growth Parameters		
Height (cm)	80±32.8	50±29.6	76±33.6
Root collar diameter (mm)	9.4±2.9	8.3±2.6	8.0±2.9
First-order lat root number	3.9±5.1	2.6±3.8	4.3±6.0
	From Bud Swelling to Bud Swelling (d)		
1st flush to 2nd flush	32.5±5.2	32.4±3.9	32.8±6.1
2nd flush to 3rd flush	32.2±4.1	35.9±6.0	33.2±3.9
3rd flush to 4th flush	33.0±4.6	35.8±5.4	33.0±3.5
4th flush to 5th flush	32.4±3.0	32.0±1.4	33.0±5.5
	Flush Length (cm)		
Epicotyl	10.3±2.1	8.0±2.3	9.1±2.0
1st flush[a]	7.9±3.2	4.6±2.4	7.1±2.5
2nd flush	16.7±5.6	14.9±6.1	14.5±5.2
3rd flush	26.2±6.4	27.0±10.0	25.2±7.1
4th flush	36.2±9.1	38.0±17.7	35.2±9.9
5th flush	31.0±9.8	26.2±4.7	27.6±8.8
	Seedling Percentage (pct)		
1st flush	99	100	100
2nd flush	98	89	98
3rd flush	87	60	88
4th flush	53	16	57
5th flush	9	2	9

[a] Mean flush length was derived from sum of flush length divided by number of seedlings with that given flush, instead of total seedling number. Therefore, sum of epicotyl length and all five flush lengths is greater than measure height.

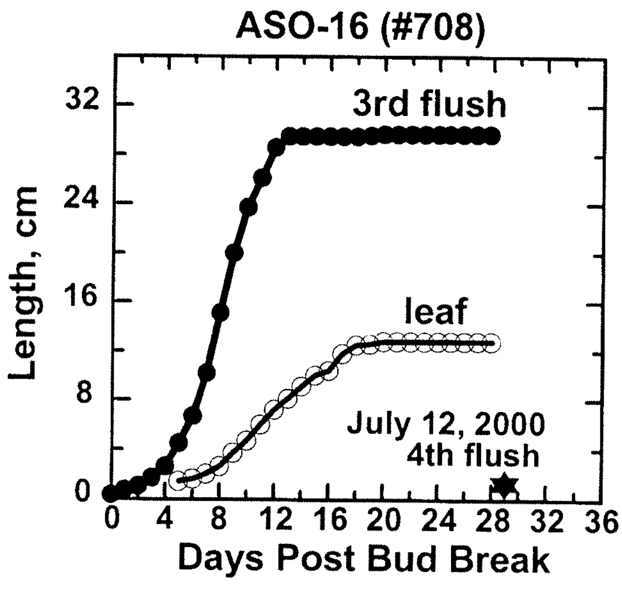


Figure 2—Daily elongation of the third flush and leaf length extension of the fourth leaf from the bottom of the third flush in a white oak seedling from family ASO-16.

seedlings selected for the Detailed Flush Development Sub-study had similar temporal patterns for flush elongation and leaf expansion curves. Generally, flush elongation was linear between 4 and 13 dpbb (figure 2). Leaf expansion lagged several days behind active flush elongation. There seemed to be a span of one week between leaf maturation and appearance of the next flush bud for most seedlings.

For the Detailed Flush Development Sub-study, only the third, fourth, fifth flush growth curves of ASO seedlings were presented in figure 3. Similar curves were observed with SRS seedlings (data not shown). Inflection points for the third, fourth, and fifth flushes of ASO seedlings were 9.7, 12.4, and 10.9 dpbb. Slopes, (i.e., elongation rates, centimeter/day), at the inflection point for the third, fourth, and fifth flush were 3.9, 3.7, and 4.6 (figure 3). Inflection point (dpbb) and its slope for the third, fourth, and fifth flushes of SRS seedlings were as follows: 9.6 and 3.4, 11.1 and 3.5, and 10.1 and 4.3, respectively. The third flush growth curve of BSO seedlings had the inflection point at 10.9 dpbb with a slope of 4.5.

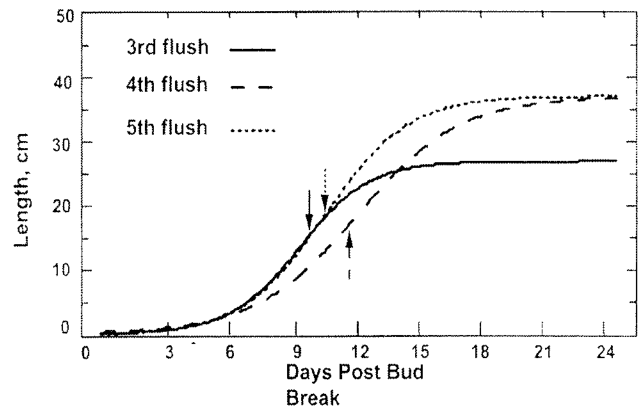


Figure 3—Logistic curves for third, fourth, and fifth flush development of the same white oak seedlings from Arrowhead Seed Orchard. The inflection points were indicated with arrows. Sixty-eight seedlings were included for the third flush development. Of these seedlings, 63 had the fourth flush and 37 produced the fifth

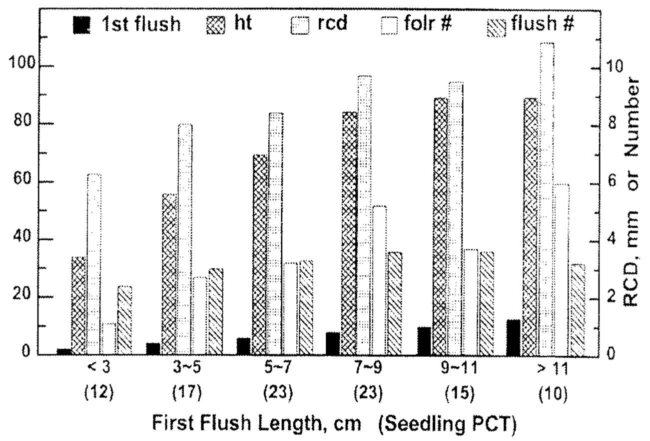


Figure 4—Growth parameter means of 520 1-0 white oak seedlings grouped by the length of their first flushes. Acorns were from 10, 5, and 5 individual mother trees at Arrowhead Seed Orchard, Beech Creek Seed Orchard, and Savannah River Site forest stands, respectively. Values in parentheses were centages of seedlings in each group.

All Flush Development Sub-study

The 520 seedlings selected for the All Flush Development Sub-study had similar height, RCD, and FOLR number to their corresponding group in the Main Study (table 3 versus figure 1). Seedlings of ASO and SRS were also comparable in all growth parameters including individual flush length and flush number (table 3). More than half of ASO and SRS seedlings had four flushes as compared to only 16 percent for BSO seedlings. Furthermore, BSO seedlings had the shortest first flushes.

First flush buds began to swell in late April. Mean julian days for swelling of the first flush buds were 118 ± 5.0, 120 ± 6.8, and 121 ± 7.7 for ASO, BSO, and SRS, respectively. A span of 33 days existed from the swelling of a flush bud to the swelling of the subsequent flush bud for all flushes of ASO and SRS seedlings (table 3). However, BSO seedlings had a span of 36 days for second to third and for third to fourth flush bud swelling. For some seedlings, when a bud appeared much later than the average bud to bud span of 33 to 36 days, these buds usually remained tight for the rest of the growing season. For all seedlings, each flush was longer than its previous flush except for flush five which was shorter than the fourth (table 3). This might be related to a shortening photoperiod during the fifth flush development in September.

It has been reported that heritability estimates are in the range of 0.55 to 0.92 with small standard errors for various oak species (Kormanik and others 1997) and loblolly pine (Kormanik and others 1990). Seedlings with many FOLR are competitors in the nursery and perform well after outplanting (Kormanik and others 1998, this proceedings). Thus, in our effort to artificially regenerate oak stands on high quality mesic sites, three criteria have been used to grade 1-0 seedlings at lifting (Kormanik and others 1997,1998,2000). They are $60 centimeter height, $7 millimeter RCD, and $ 5 FOLR for white oak (Kormanik and others 2000). The mean FOLR was suggested to be the most important seedling selection criterion (Kormanik and others, 1997, 1998, 2000). In this study, mean FOLR for ASO and SRS was about 4 (table 2). Mean FOLR for BSO was 2.6. Seedlings which met at least two of the three criteria, namely $ mean FOLR, $ 8 millimeter RCD, and $ 70 centimeter height were outplanted on various National Forests in Georgia, South Carolina, North Carolina, and Tennessee in February 2001 for seed orchard establishment. Field performance of these seedlings will be followed over time.

Figure 4 presents the 520 seedlings in the All Flush Development Sub-study based on their first flush length. It is evident that seedlings with first flushes shorter than 5 centimeter did not meet two of our three nursery grading standards. About forty percent of the seedlings were evaluated as low quality stocks (figure 4). Since most seedlings finished their first flush elongation by mid-May, it might be feasible to assess the quality of first year nursery-grown seedlings by mid-May. All seedlings in this sub-study were transplanted into nearby nursery beds at Whitehall Experiment Forest. Their performance also will be monitored.

Combining the data of germination percent, seedling morphology (such as albino leaf), and first flush length, one should be able to identify competitive progeny before June. For example, most seedlings from BSO had first flush lengths shorter than 5 centimeter, mean heights less than 70 centimeter, and germination rates less than 80 percent (tables 1, 3). Acorns from these grafted mother trees should not be collected in the future for artificial oak regeneration. Our future study will test the following two hypotheses: that heritability estimates for first flush length of 1-0 nursery-grown oak seedlings are similar to those for FOLR number and that there are high correlations between these two parameters. In addition to FOLR number, first flush length might be a good indicator of seedling competitiveness and performance in the nursery and field.

LITERATURE CITED

Hodges, J.; Gardiner, E.S. 1993. Ecology and physiology of oak regeneration. In: Loftis, D.L.; McGee, C.E. ed. Symposium Proceedings. Oak regeneration: serious problems, practical recommendations. 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station:54-56.

Kormanik, P.P.; Ruehle, J.L.; Muse, H.D. 1990. Frequency distribution and heritability of first-order lateral roots in loblolly pine seedlings. Forest Science 36: 802-814.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. 1994. Toward a single nursery protocol for oak seedlings. In: Proceedings 22nd southern forest tree improvement conference, 1993 June 14-17, Atlanta, Ga: 114-123.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. (and others) 1995. Effect of apical meristem clipping on carbon allocation and morphological development of white oak seedlings. In: Edwards, M. B., ed. Proceedings of the eighth biennial southern silvicultural research conference; 1994 November 1-3; Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 332-337.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. (and others) 1997. Heritability of first-order lateral roots in five *Quercus*: Effect on 1-0 seedling quality evaluation. In: Steiner, K.C., ed. Diversity and Adaptation in Oak Species. Proceedings of the second meeting of IUFRO Working Party 2.08.05, Genetics of *Quercus*. 1997 October 12-17. The Pennsylvania State University, University Park, PA: 194-200.

Kormanik, P.P.; Sung, S.S.; Kass, D.J. (and others) 1998. Effect of seedling size and first-order lateral roots on early development of northern red oak on mesic sites. In: Waldrop, T.A., ed. Proceedings of the ninth biennial southern silvicultural research conference; 1997 February 25-27; Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 247-252.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. (and others) 2000. Heritability of first-order lateral rot number in *Quercus*: implication for artificial regeneration of stands. In: Stokes, Alexia, ed. Supporting Roots of Trees and Woody Plants: Form, Function and Physiology. Developments in Plant and Soil Sciences 87:171-178. Kluwer Academic Publishers, The Netherlands.

Loftis, D.L. 1983. Regenerating Southern Appalachian mixed hardwoods with the shelterwood method. Southern Journal of Applied Forestry 7: 212-217.

Loftis, D.L. 1990. Predicting post harvest performance of advanced red oak production in the southern Appalachians. Forest Science 36: 908-916.

Lorimer, C.G. 1993. Causes of the oak regeneration problems. In: Loftis, D.L.; McGee, C.E. ed. Symposium Proceedings. Oak regeneration: serious problems, practical recommendations. 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 14-39.

Sanders, I.L.; Clark, F.B. 1971. Reproduction of upland hardwood forests in the central states. Agriculture Handbook 405, U.S. Department of Agriculture, Forest Service, Washington, DC, 25 p.

SAS Institute Inc. 1989. SAS/STAT User's Guide, Version 6, Fourth Edition, Volume 2, Cary, NC: SAS Institute Inc. 846 p.

HAND PLANTING VERSUS MACHINE PLANTING OF BOTTOMLAND RED OAKS ON FORMER AGRICULTURAL FIELDS IN LOUISIANA'S MISSISSIPPI ALLUVIAL PLAIN: SIXTH-YEAR RESULTS

Alexander J. Michalek, Brian Roy Lockhart, Thomas J. Dean, Bobby D. Keeland, and John W. McCoy[1]

Abstract—Interest in restoring bottomland hardwoods on abandoned agricultural fields has gained considerably over the past 15 years, due primarily to federal cost-share programs such as the Conservation Reserve Program and the Wetlands Reserve Program. While a variety of artificial regeneration techniques are available to afforest these lands, none have met with consistently successful results, especially in the Mississippi Alluvial Plain. Therefore, a study was initiated to compare a variety of regeneration techniques for afforesting previously farmed bottomland hardwood sites. In this paper we report the results from hand planted versus machine planted 1-0 bare-root bottomland red oak seedlings. Four sites in the MAP in Louisiana were planted with either 1 or 2 species in a randomized complete block design. Sites and species planted included Bayou Macon Wildlife Management Area [WMA; Nuttall oak (*Quercus nuttallii* Palmer) and willow oak (*Q. phellos* L.)], Lake Ophelia National Wildlife Refuge (NWR; Nuttall oak), Ouachita WMA (willow oak), and the Tensas NWR [Nuttall oak and water oak (*Q. nigra* L.)]. Results after 6 growing seasons indicated little difference in density, survival, planting success, and stocking between planting methods. Densities ranged from 280 Nuttall oak seedlings per acre machine planted at the Tensas NWR to 67 willow oak seedlings per acre machine planted at the Bayou Macon WMA. Nuttall oak also tended to have higher survival (81 percent) compared to willow oak (56 percent) and water oak (38 percent). When volunteer oak and ash were included, all site-species-planting method combinations met the minimum criteria for successful afforestation, but all combinations failed to meet minimum stocking levels necessary for quality sawtimber production.

INTRODUCTION

Interest in restoring bottomland hardwood forests on former agricultural land (afforestation) has increased considerably over the past 15 years (Allen and Kennedy 1989, Schweitzer and Stanturf 1997, Gardiner and others In press). This interest on private lands has coincided with the advent of several government cost-share programs that provide financial assistance to establish trees on these lands; chief among these programs are the Conservation Reserve Program and the Wetlands Reserve Program (WRP) (Cubbage and Gunter 1987, Kennedy 1990). Interest in restoring bottomland hardwood forests on public lands is due to the recognized importance of these forests for their various wildlife habitat functions and values (Richardson 1994). Nearly 100,000 acres of former agricultural land had been afforested in the Mississippi Alluvial Plain (MAP) of Arkansas, Louisiana, and Mississippi by 1995 with potentially another 110,000 acres by 2005 (Stanturf and others 1998).

Common afforestation techniques involve either planting seedlings or sowing seed, particularly oak (*Quercus* spp.) acorns (Stanturf and others 1998, Gardiner and others In press). Much debate has existed concerning which technique is superior to ensure greatest success of afforestation efforts. Sowing seed is often touted as an easier and cheaper afforestation technique than planting seedlings (Bullard and others 1992). Direct seeding also has a larger planting window compared to planting seedlings (Johnson 1983). Likewise, advantages to planting seedlings include an easier evaluation of the planting operation, and potentially greater survival and growth (Ozalp and others 1998). Because past experience with direct seeding has not been as successful as desired, several state agencies require that seedlings be used to qualify for government cost-share programs (Mr. Larry Nance, Arkansas Forestry Commission, Little Rock, AR, pers. comm.).

The question that arises once a decision has been made to plant seedlings is whether to hand plant or machine plant. A common recommendation is to machine plant if possible because machine planting can substantially speed up the planting job in soils other than heavy clays (Allen and Kennedy 1989). It is commonly cited that one person can hand plant between 600-800 hardwood seedlings per day if conditions are good (Allen and Kennedy 1989, Kennedy 1990, Kennedy 1993) while an experienced crew of two or three people can machine plant 4,000-10,000 hardwood seedlings per day (Kennedy 1990, Kennedy 1993, Stanturf and others 1998). Many of the comments regarding hand planting or machine planting oak seedlings on bottomland sites are based on personal

[1]Graduate Research Assistant and Associate Professors, School of Forestry, Wildlife, and Fisheries, Louisiana State University, Baton Rouge, LA 70803; Research Ecologist and General Biologist, USGS, National Wetlands Research Center, Lafayette, LA 70506, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

observations or results with planting pine (*Pinus* spp.) species on upland sites (Ezell 1987, Long 1991). Little work has focused on direct comparisons of hand versus machine planting hardwood seedlings on bottomland sites (Russell 1997, Russell and others 1998). The objective of this research was to compare hand versus machine planting of several bottomland red oak species on former agricultural fields at different locations in the MAP in Louisiana. Sixth-year post-planting results are presented.

MATERIALS AND METHODS

Locations

The study was conducted on abandoned agricultural fields at 4 locations in Louisiana's MAP. Though none of these sites receive direct flooding from a major river system (i.e., the Mississippi River or the Red River), each site floods from localized weather events and backwater of minor rivers and bayous. Each site is described separately below.

The Bayou Macon Wildlife Management Area (WMA) is located in East Carroll Parish in northeast LA. The study site is located about 2.5 miles east of Bayou Macon, north of East Carroll Parish Highway 3330. The forest was cleared in the 1960s and planted to agricultural crops. The area was purchased in 1991 by the Louisiana Department of Wildlife and Fisheries (LDWF) and converted into a state wildlife management area. Soils are Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) based on a detailed survey by National Resource Conservation Service (NRCS) personnel (NRCS soil survey field notes for each site are on file with the School of Forestry, Wildlife, and Fisheries (SFWF), Louisiana State University (LSU), Baton Rouge, LA) with an estimated site index, based age 50 years, of 90 for Nuttall oak (*Q. nuttallii* Palmer) (Baker and Broadfoot 1979).

The Lake Ophelia National Wildlife Refuge (NWR) is located in Avoyelles Parish in east-central LA. The study site is located 2-4 miles, depending on replication, from the Red River and is protected from river flooding by the main-line levee system. The forest on this site was cleared in the 1960s and planted to agricultural crops. The area was purchased by the U.S. Department of Interior Fish and Wildlife Service (FWS) and converted to a federal national wildlife refuge. Soils are of the Tensas/Sharkey complex (Tensas silty clay - fine, smectitic, thermic Aeric Epiaqualfs) with the former soil occupying ridges and the latter occupying lower elevation areas. Nuttall oak site index was estimated to be 90 (Baker and Broadfoot 1979).

The Ouachita WMA is located in Ouachita Parish in northeast LA. The study site is located about six miles southeast of Monroe, LA south of Highway 15 near the Bayou LaFourche River. The forest on this site was cleared in the 1960s or 1970s and planted to agricultural crops. The area was purchased in 1984 by the LDWF and converted to a state wildlife management area. Soils are a mixture of Portland silty clay (very-fine, mixed, nonacid, thermic Vertic Haplaquepts) and Hebert silt loam (fine-silty, mixed, thermic Aeric Ochraqualfs). Inspection of the soil prior to study establishment indicated that the Herbert silt loam is shallow (8-9 inches) and turns powdery when dry. This soil is underlain by the Portland clay. Nuttall oak site index was estimated to be 85 (Baker and Broadfoot 1979).

The Tensas NWR is located in Madison Parish in northeast LA. The study site is located about seven miles south of Interstate 20, three miles northeast of the refuge headquarters, and about one mile east of the Tensas River. The forest on this site was cleared in 1970s and planted to agricultural crops. The area was eventually purchased by the FWS and converted to a federal wildlife refuge. Soils are of the Tensas/Sharkey complex as previously described. Nuttall oak site index was estimated to be 90 (Baker and Broadfoot 1979).

Planting Methods/Design

As part of a larger afforestation study, 14 combinations of direct seeding and planting seedling treatments were utilized (see McCoy and others (2002) in this conference proceedings for a complete description of the direct seeding treatments). Two of these 14 combinations involved hand planting and machine planting of 1-0 red oak seedlings. These two treatments are the focus of this paper.

At each study site, 1-acre square treatment plots (209 feet on each side) were laid out for each treatment. Each plot was surrounded by a 33-foot buffer zone to allow equipment to turn around without affecting neighboring plots. For the seedling planting treatments, each plot was tilled in the Fall 1993 prior to planting. Bare-root, 1-0 planting stock purchased from the LA Department of Agriculture and Forestry's Columbia Nursery was used at each site. Three red oak species were utilized in the study: Nuttall oak and willow oak (*Q. phellos* L.) at the Bayou Macon WMA, Nuttall oak at the Lake Ophelia NWR, willow oak at the Ouachita WMA, and Nuttall oak and water oak (*Q. nigra* L.) at the Tensas NWR. Nuttall oak was the primary species used due to proven success at various afforestation sites throughout the MAP. The other species were chosen based on site conditions, and to compare with Nuttall oak if space at the site permitted. Planting was done in January or February, 1994 at each site. The target spacing was 12 feet by 12 feet or 302 seedlings for the 1-acre plot. The general design was to plant 17-18 seedlings in each of 17 rows (289-306 seedlings per acre). Hand planting was conducted using dibble bars. Machine planting was done using a lift planter on the state wildlife management areas which made furrows 6-10 inches deep (averaged 8 inches) depending on soil moisture conditions. Machine planting on the national wildlife refuges was done using a FESCO planter. While a general plan for planting was developed, final planting operations were conducting by officials associated with each wildlife management area or national wildlife refuge. The purpose for this decentralized control was to make operations as practical and applicable as possible, but problems did occur. Weather conditions at several sites resulted in machine planting being conducted under wet conditions. Such conditions, combined with the heavy clay soils, resulted in clay clogging the planting machine and some seedlings not being planted optimally. Furthermore, the target spacing was not always obtained due to mechanical problems with the machine planter, site conditions, and the way planted seedlings were counted.

Measurements and Analyses

Measurements for each of the 4 study sites were conducted during November 1999, 6 growing seasons after planting. Four 0.025-acre (0.01-ha) circular plots were established 20 meters diagonally from each of the four corners for each square 1-acre treatment plot. In each measurement plot, all tree seedlings and saplings (including natural reproduction) were tallied in 1 of 6 size classes by species: 0-30 cm tall, 30-50 cm, 50-100 cm, 100-140 cm, 140 cm - 2.5 cm dbh, and > 2.5 cm dbh. These size classes correspond to a standard sampling protocol used by the USGS Wetlands Research Center in Lafayette, Louisiana. A pvc stake flag was placed at each measurement plot center and electronic measuring devices were used to circle the plot while tallying trees by size class.

Analyses involved determining density, survival, and success of oak species planted in each plot, and stocking values of desired species (both planted oaks and volunteer oaks and green ash). All plot-level counts were converted to per-acre values and averaged across each plot to obtained density (number of stems per acre) by size class. Size classes were then summed to obtain total number of stems by plot. Survival was calculated by dividing the density counts by the actual number of seedlings planted, while planting success was calculated by dividing the density counts by the target number of seedlings planted (302 per acre). Stocking values were determined by assigning point values to each size class following Johnson's (1980) bottomland hardwood regeneration evaluation model as updated by Hart and others (1995). Size-class counts were done using the metric system of units while the bottomland hardwood regeneration evaluation model used English units. Therefore, the following points were assigned to each size class for oak and ash, respectively: (1) 0-30 cm; 0.5 points for both, (2) 30-50 cm and 50-100 cm; 2 and 6 points, and (3) 100-140 cm, 140 cm - 2.5 cm dbh, and >2.5 cm dbh; 3 and 6 points. This point assignment closely follows those developed by Hart and others (1995) using size classes based in English units. Each plot was considered stocked if it contained ≥ 12.0 points for a 0.01-acre plot. Density counts were adjusted from the 0.01-ha measurement plot to a 0.01-acre plot. Analysis-of-variance using a randomized complete block design with 3 replications per site and planted species was used to compare hand planting and machine planting treatments by site. Blocking was done by elevation of the site, i.e., ridges, flats, etc. Variables analyzed included density, survival, planting success, points, and stocking. Analyses were conducted using PC-SAS and an alpha level of 0.05 was used to determine significant differences (SAS 1985).

RESULTS AND DISCUSSION

Density

Seedling density, 6 growing seasons after planting ranged from 280 per acre for machine-planted Nuttall oak on the Tensas NWR site to 67 per acre for machine-planted willow oak on the Bayou Macon WMA site (table 1). Only one significant difference was found between planting methods with hand-planted willow oak having a greater density than machine-planted willow oak (table 1). In general, Nuttall oak plantings resulted in greater densities than the other oak species, especially when planted on the same site.

WRP guidelines state that for a site to be considered successfully afforested 125 stems per acre (either planted or natural) must be present 3 years after planting. Seventy-five percent of the site-species-treatment combinations met this minimum although these densities represent 6 years after planting instead of 3 years. Of interest is that all the Nuttall oak site-planting method combinations met this criteria, while only 3 of the 6 other site-species-planting method combinations met this criteria. When volunteer oaks and green ash were included in density calculations, all sites met the 125 stems per acre WRP minimum criteria for successful afforestation.

Survival

Survival 6 years after planting ranged from 97 percent for machine planted Nuttall oak on the Tensas NWR to 26 percent for machine planted willow oak on the Bayou Macon WMA (table 1). As with density, Nuttall oak tended to perform better than either willow oak or water oak when planted on similar sites. This was especially true for the Tensas NWR site. Nuttall oak averaged 92 percent survival across treatments while water oak averaged only 38 percent.

Various factors may have influenced these survival values. First, the sampling protocol involved 4 subplots for each treatment plot. Standard error values associated with each survival value ranged from 3 for hand-planted willow oak to 16 for hand-planted Nuttall oak, both on the Bayou Macon WMA. Sampling error must be taken into account when interpreting these survival values (table 1). Second, state wildlife management areas and federal wildlife refuges were planted by personnel associated with each agency. On several sites, the number of seedlings planted was calculated by subtracting the number of seedlings left in nursery package bags from an assumed total number of seedlings in the bag prior to planting. This assumption was not always correct as seedling counts in several bags was less than indicated on the bag label. A third factor involved seedling quality. Planting records indicated that several seedlings were simply too small (less than 18 inches in height and 0.5-0.75 inches in root-collar diameter). Small seedlings planted in abandoned agricultural fields are at a disadvantage to competing vegetation due to less stored food reserves in the root system. Another seedling quality issue was mixing of species. It was noted in the records that water oak seedlings were mixed with the willow oak seedlings at the nursery; therefore, some water oak was planted in willow oak treatment plots. Water oak, being less flood tolerant than willow oak, would be expected to have higher mortality rates on several of the sites used in this study.

Success

Regeneration success evaluates the current density of seedlings and saplings compared to the target planting rate set prior to the planting operation. If the target rate is met during the planting operation then survival and success are the same measures. But rarely does operational planting meet target rates; therefore, regeneration success may be a better criteria to evaluate the longer-term results of afforestation efforts. Regeneration success closely followed survival

Table 1—Sixth year density, survival, regeneration succuss, and stocking by site, species, and planting method for bottmland red oaks planted on abandoned agricultural fields in Louisiana's Mississippi Alluvial Plain Numbers in parentheses represent one standard error[a]

Site	Species	Planting Treatment	Initial Density	1999 Density	Survival	Success	Points	Stocked Plots	WRP Success
			stems/ac	stems/ac	percent	percent	unitless	percent	
Bayou Macon WMA	Nuttall oak	hand	300 (2)	226 (47)	75 (16)	75 (16)	13.0 (2.7)	42	yes
		machine	286 (10)	250 (9)	87 (4)	83 (3)	10.4 (0.9)	25	yes
	willow oak	hand	281 (2)	148 (9)	53 (3)	49 (3)	14.7 (2.8)	50	yes
		machine	269 (11)	67 (27)	26 (11)	22 (9)	7.4 (4.0)	17	no
Lake Ophelia NWR	Nuttall oak	hand	330a (0)	169 (29)	51 (9)	56 (10)	4.7 (0.6)	0	yes
		machine	306b (0)	273 (20)	89 (7)	90 (7)	10.4 (1.3)	25	yes
Ouachita WMA	willow oak	hand	297 (1)	233a (21)	78 (7)	77a (7)	6.5a (0.6)	0	yes
		machine	276 (21)	185b (17)	68 (8)	61b (6)	5.2b (0.6)	0	yes
Tensas NWR	Nuttall oak	hand	289 (0)	253 (36)	88 (12)	84 (12)	11.2 (2.2)	33	yes
		machine	289 (0)	280 (38)	97 (13)	93 (12)	10.8 (1.1)	33	yes
	water oak	hand	289 (0)	101 (16)	35 (5)	34 (5)	7.1 (2.9)	17	no
		machine	289 (0)	121 (23)	42 (8)	40 (8)	6.9 (1.4)	17	no

[a]Numbers followed by different letters within a site, species, planting combination are significantly different at p = 0.05

trends in this study (table 1). Initial planting density usually did not reach the target density of 302 seedlings per acre (table 1). On several sites, initial density was as low as 90 percent of the target planting density. Variable initial density resulted from difficult planting conditions for machine planting on several sites and simply running out of seedlings. Regeneration success though was not well correlated with the initial density. The highest initial density, 330 hand-planted Nuttall oak on the Lake Ophelia NWR, had only 56 percent success 6 years later. Obviously, other factors are involved in the success of artificial regeneration efforts than simply how many seedlings are initially planted.

Stocking

Johnson (1980) initially developed a regeneration evaluation system for bottomland hardwoods. Points were assigned to regeneration present before a harvest (advance regeneration) based on their size and to trees based on their stump sprouting potential. Using 0.01-acre circular plots, points would be summed for desirable species until a minimum threshold of 12 points was reached. Once 12 points was obtained then the plot was considered fully stocked with desirable species. This regeneration evaluation system was develop for natural regeneration of pre-existing bottomland hardwood stands with a management objective of growing high-quality sawlogs. The system was later modified by Hart and others (1985) and Belli and others (1999) based on additional research into the regeneration dynamics of bottomland red oaks and green ash following harvesting. While developed for pre-existing stands, this regeneration evaluation system may be applied to afforested situations because we believe that stocking principles, such as points by size class and distribution of stocked plots, are similar regardless of stand initiation conditions.

The average number of points scored by treatment ranged from 14.7 for the hand-planted willow oak on the Bayou Macon WMA to 5.2 for machine-planted willow oak on the Ouachita WMA (table 1). The latter site was the only one in which a significant difference in the number of points occurred with hand-planted plots having more points than machine-planted plots. In general, sites planted with Nuttall oak scored better than sites planted with either willow oak or water oak. Only 2 of the > 12 site-species-planting method combinations averaged points 12, the Bayou Macon WMA hand-planted Nuttall oak and willow oak treatments. Plots on this site tended to have a significant component of natural green ash that was distributed from an adjacent stand. The remaining 10 combinations scored less than the minimum necessary to be considered fully stocked although four of these combinations average > 10 points.

Hart and others (1995) warned not to average points across plots because an average score may indicate that regeneration may be adequate when in reality only a few plots had considerably greater than average points that skewed the average score higher. Hart and others (1995) recommended a more appropriate application of the regeneration evaluation system would be to determine the percentage of plots that met the minimum threshold of 12 points. Johnson and Deen (1993) recommended that 60-70 percent of the plots needed to meet the 12-point minimum for the site to be considered adequately stocked. The number of plots meeting this criteria ranged from 0-50 percent across the site-species-treatment combinations (12 regeneration plots for each site-species-planting method combination for a total of 144 plots; table 1); therefore, none of the areas that were planted, regardless of planting method, would be considered successfully regenerated after 6 growing seasons if the primarily objective was quality sawtimber production.

CONCLUSIONS

Little difference was found in the density, survival, and planting success of bottomland red oak seedlings and stocking of oak and ash seedlings and saplings between hand planted and machine planted treatments 6 years after planting. But, according to notes taken during planting operations (notes on file at the SFWF, LSU) and discussions with personnel who conducted the planting operations, machine planting conditions were less than ideal. Officials with the LDWF indicated that when planting operations are under ideal conditions, i.e., soils are neither too wet or too dry, they consistently get 5-10 percent greater survival for machine planting compared to hand planting (Kenny Ribbeck and Buddy Duprey, LDWF, Baton Rouge and Pineville, LA, respectively). Others have also found greater survival of machine planted bottomland red oak species when compared to hand planting (Russell and others 1998). Results from this study indicate that various considerations, such as site conditions and costs, are necessary in determining whether to machine plant or hand plant bottomland red oak seedlings.

A second observation from this study was the success or failure of the treatments depended on the afforestation objective(s). Although 6-year results were presented, all site-species-planting method combinations met the minimum density required by the WRP program (keeping in mind that WRP success is based on third-year post-planting observations). Success was obtained with only the planted oaks and volunteer oaks and green ash. Other species were found in the measurement plots (see McCoy and others (2002) in this conference proceedings), further solidifying WRP success. Concurrently, all site-species-planting method combinations failed to meet stocking criteria for quality sawlog production, even when volunteer oak and ash were included in stocking calculations. The important point is that specific management objective(s) should be developed before afforestation activities commence.

A third observation from this study was that Nuttall oak consistently outperformed willow oak and water oak. On heavy clay soils, such as those found in the MAP, Nuttall oak is often the preferred species, due to its greater flood tolerance, on these potentially harsh sites. Results from this study confirm other observations and studies that Nuttall oak is a preferred species for afforesting abandoned agricultural fields with clay soils in the MAP (Stanturf and others 1998). It is very important that only quality hardwood seedlings are purchased from nurseries, that species are properly matched to site conditions, and that constant oversight is conducted during planting operations. Attention to these factors will increase the success of any afforestation effort on bottomland sites (Gardiner and others (In press), Stanturf and others 1998).

ACKNOWLEDGMENTS

The authors thank the Louisiana Department of Wildlife and Fisheries and the U.S.D.I. Fish and Wildlife Service for their support in providing the land and installing this study. Emile Gardiner provided constructive comments on an earlier draft of this manuscript.

REFERENCES

Allen,J.A.; Kennedy, H.E., Jr. 1989. Bottomland hardwood reforestation in the lower Mississippi Valley. Bulletin. Slidell, LA: U.S. Department of Interior, Fish and Wildlife Service. 28 p.

Baker, J.B.; Broadfoot, W.M. 1979. A practical field method of site evaluation for commercially important southern hardwoods. Gen. Tech. Rpt. SO-26. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 51 p.

Belli, K.L.; Hart, C.P.; Hodges, J.D.; Stanturf, J.A. 1999. Assessment of the regeneration potential of red oaks and ash on minor bottoms of Mississippi. Southern Journal of Applied Forestry. 23: 133-138.

Bullard, S.; Hodges, J.D.; Johnson, R.L.; Straka, T.J. 1992. Economics of direct seeding and planting for establishing oak stands on old-field sites in the South. Southern Journal of Applied Forestry. 16: 34-40.

Cubbage, F.W.; Gunter, J.E. 1987. Conservation reserves: can they promote wildlife habitat and tree crops while protecting erodible soil? Journal of Forestry. 85: 21-27.

Ezell, A.W. 1987. The pine planting decision: hand versus machine planting methods. Forest Farmer. 41(1): 8-10.

Gardiner, E.S.; Russell, D.R.; Oliver, M.; Dorris,L.C., Jr. In press. Bottomland hardwood afforestation: state of the art. Proceedings of the Conference on Sustainability of Wetlands and Water Resources; 2000 May 21-23; Oxford, AL.

Hart, C.P.; Hodges, J.D.; Belli, K.L.; Stanturf, J.A. 1995. Evaluating potential oak and ash regeneration on minor bottoms in the Southeast. In: Edwards, M. Boyd, comp. Proceedings of the eighth biennial southern silvicultural research conference; 1994 November 1-3; Auburn, AL. Gen. Tech. Rpt. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 434-442.

Johnson, R.L. 1980. New ideas about regeneration of hardwoods. In: Proceedings, Hardwoods regeneration symposium;1980 January 29;Atlanta.Forest Park, GA: Southeastern Lumber Manufacturing Association: 17-19.

Johnson, R.L. 1983. Nuttall oak direct seedings still successful after 11 years. Res. Note SO-301. New Orleans:U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 3 p.

Johnson, R.L.; Deen, R.T. 1993. Prediction of oak regeneration in bottomland forests. In: Loftis,David L.; McGee,Charles E., eds. Oak regeneration: serious problems, practical recommendations: Symposium proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 146-155.

Kennedy, H.E., Jr. 1990. Hardwood reforestation in the South: landowners can benefit from Conservation Reserve Program incentives. Res. Note SO-364. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 6 p.

Kennedy, H.E., Jr. 1993. Artificial regeneration of bottomland hardwoods. In: Loftis,David L.; McGee,Charles E., eds. Oak regeneration: serious problems, practical recommendations: Symposium proceedings; 1992 September 8-10; Knoxville, TN. Gen.Tech.Rep.SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 241-249.

Long, A.J. 1991. Proper planting improves performance. In: Duryea,M.L.; Dougherty,P.M., eds. Forest regeneration manual. Kluwer Academic Publishers, Dortrecht, The Netherlands: 303-321.

McCoy, J.W.; Keeland, B.D.; Lockhart, B.R.; Dean, T.J. 2002. Pre-planting site treatments and natural invasion of tree species onto former agricultural fields at the Tensas River National Wildlife Refuge, Louisiana. [This proceedings].

Ozalp, M.; Schoenholtz, S.H.; Hodges, J.D.; Miwa, M. 1998. Influence of soil series and planting methods on fifth-year survival and growth of bottomland oak re-establishment in a farmed wetland. In: Waldrop, Tom A., comp. Proceedings of the ninth biennial southern silvicultural research conference; 1997 February 25-27; Clemson, SC. Gen. Tech. Rpt. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 277-280.

Richardson, C.J. 1994. Ecological functions and human values in wetlands: a framework for assessing forestry impacts. Wetlands. 14: 1-9.

Russell, D.R., Jr. 1997. An evaluation of hardwood reforestation methods on previously farmed lands in central Alabama. Unpublished Masters thesis. Mississippi State, MS: Mississippi State University. 57p.

Russell, D.R.; Hodges, J.D.; Ezell, A.W. 1998. An evaluation of hardwood reforestation methods on previously farmed lands in central Alabama. In: Waldrop, Tom A., comp. Proceedings of the ninth biennial southern silvicultural research conference; 1997 February 25-27; Clemson, SC. Gen. Tech. Rpt. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 272-276.

SAS. 1985. SAS/STAT guide for personal computers, version 6. SAS Cary, NC: SAS Institute, Inc. 378 p.

Schweitzer, C. J.; J. A. Stanturf. 1997. From okra to oak: reforestation of abandoned agricultural fields in the Lower Mississippi Alluvial Valley. In: Meyer, Dan E., ed. Proceedings of the 25th annual hardwood symposium, 25 years of hardwood silviculture: a look back and a look ahead; 1997 May 7-10; Cashiers, NC. Memphis, TN: National Hardwood Lumber Association: 131-138.

Stanturf, J.A.; Schweitzer, C.J.; Gardiner, E.S. 1998. Afforestation of marginal agricultural land in the Lower Mississippi River Alluvial Valley, U.S.A. Silva Fennica. 32: 281-297.

SUPPLEMENTAL PLANTING OF EARLY SUCCESSIONAL TREE SPECIES DURING BOTTOMLAND HARDWOOD AFFORESTATION

Daniel J. Twedt and R. Randy Wilson[1]

Abstract—Reforestation of former bottomland hardwood forests that have been cleared for agriculture (i.e., afforestation) has historically emphasized planting heavy-seeded oaks (*Quercus* spp.) and pecans (*Carya* spp.). These species are slow to develop vertical forest structure. However, vertical forest structure is key to colonization of afforested sites by forest birds. Although early-successional tree species often enhance vertical structure, few of these species invade afforested sites that are distant from seed sources. Furthermore, many land mangers are reluctant to establish and maintain stands of fast-growing plantation trees. Therefore, on 40 afforested bottomland sites, we supplemented heavy-seeded seedlings with 8 patches of fast-growing trees: 4 patches of 12 eastern cottonwood (*Populus deltoides*) stem cuttings and 4 patches of 12 American sycamore (*Platanus occidentalis*) seedlings. To enhance survival and growth, tree patches were subjected to 4 weed control treatments: (1) physical weed barriers, (2) chemical herbicide, (3) both physical and chemical weed control, or (4) no weed control. Overall, first-year survival of cottonwood and sycamore was 25 percent and 47 percent, respectively. Second-year survival of extant trees was 52 percent for cottonwood and 77 percent for sycamore. Physical weed barriers increased survival of cottonwoods to 30 percent versus 18 percent survival with no weed control. Similarly, sycamore survival was increased from 49 percent without weed control to 64 percent with physical weed barriers. Chemical weed control adversely impacted sycamore and reduced survival to 35 percent. Tree heights did not differ between species or among weed control treatments. Girdling of trees by deer often destroyed saplings. Thus, little increase in vertical structure was detected between growing seasons. Application of fertilizer and protection via tree shelters did not improve survival or vertical development of sycamore or cottonwood.

INTRODUCTION

Throughout the world, and specifically within the southeastern United States, forested wetlands have been lost (Turner and others 1981, Noss and others 1995). Within the Mississippi River floodplain, over 7 million ha of bottomland hardwood forest have been lost (Knutson and Klaas 1998, Twedt and Loesch 1999). Most of this land is now used for agriculture, but continued intermittent flooding and unfavorable agricultural prices often result in marginal profitability. The uncertainty of financial return and concurrent environmental concerns associated with the loss of forested wetlands have prompted conservation initiatives to reverse the loss of forested wetlands throughout the United States and particularly within the Mississippi Valley (Lower Mississippi Valley Joint Venture Management Board 1990, Creasman and others 1992, Mueller and others 2000). Spurred by both economic considerations and increased awareness of the ecological and societal benefits afforded by forested wetlands, >180,000 ha currently in agricultural production are anticipated to be afforested within the Mississippi Alluvial Valley by 2005 (Stanturf and others 1998).

The ecology of bottomland hardwood forests reveals succinct successional progressions influenced by soil and hydrology (Hodges 1997) and high species diversity (Allen 1997). Despite the temporal and taxonomic diversity within bottomland hardwood forests, afforestation of bottomland sites on public lands and on private lands, through forest easements, has historically emphasized planting seedlings of heavy-seeded hardwood species such as oaks (*Quercus* spp.) and pecans (*Carya* spp.) or sowing seeds (acorns) of these species. Indeed, oaks and sweet pecan (*Carya illinoensis*) have been planted on nearly 80 percent of all afforestation in the Mississippi Alluvial Valley (King and Keeland 1999).

Planting predominantly oaks in bottomland restorations is intended to provide a "jump-start" for succession toward seasonally wet oak-hardwood forests (Kennedy and Nowacki 1997) that have oaks as dominant canopy species. This species selection has been justified because of high value of subsequent timber harvest, potential mast production for wildlife food, and an assumption that light-seeded species would naturally colonize these afforested sites. However, sites planted with only heavy-seeded species are slow to develop vertical forest structure, often requiring 7 to 10 years to emerge from the competing herbaceous vegetation. Vertical forest structure is a key predictor of colonization by forest breeding birds (Twedt and Portwood 1997, Wilson and Twedt In Press).

[1]Wildlife Biologist and Ecologist, USGS-Patuxent Wildlife Research Center, 2524 South Frontage Road, Suite C, Vicksburg, MS 39180, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

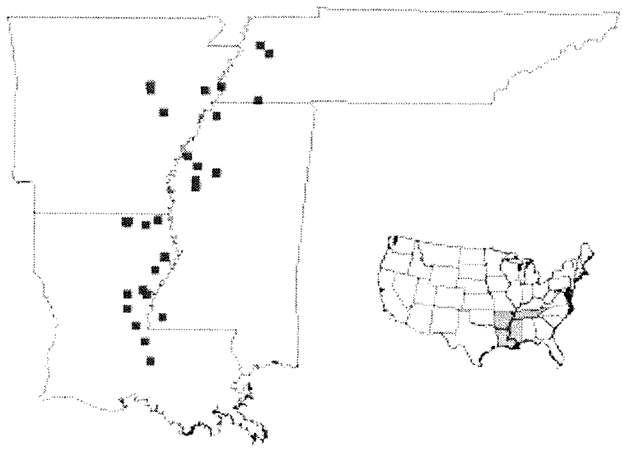


Figure 1—Location of afforested study sites in which we provided supplemental patches of fast-growing trees to enhance habitat for forest birds.

When distance from existing seed sources (i.e., mature trees) is >100 m, woody species (both light- and heavy-seeded) are insignificant invaders (Allen 1990, Wilson and Twedt In Press). This is particularly true in some areas of the Mississippi Alluvial Valley where afforestation occurs several km from extant forests and in areas no longer subject to periodic inundation from flood events that transport seeds. Lack of naturally invading early-successional tree species further restricts the development of vertical forest structure. Under these time and distance constraints, afforested sites may remain inhospitable to colonizing forest avifauna for up to 20 years.

A further limitation on the rapid growth of trees on afforested sites is that typically no weed control is provided for these plantings. The lack of weed suppression, or any other intermediate silvicultural management, has been attributed to limited financial and personnel resources. However, substantial competition from weeds may induce significant mortality of some species of fast-growing trees (Ezell 1994). Given their inability to provide weed control, managers are reluctant to risk increased tree mortality by planting susceptible species.

Regardless of which tree species are planted, species must be compatible with on-site edaphic and hydrologic conditions. However, with species selections that match site conditions, we believe that afforestation that incorporates fast-growing tree species is more conducive than historical afforestation practices to colonization by forest birds (Twedt and Portwood 1997, Twedt and Portwood, in press). Production of short-rotation woody crops, "under-planted" with other forest species, is one agroforestry option that rapidly produces forest conditions. Intercropping or alley cropping (i.e., growing agricultural crops between tree rows) using wide (> 12 m) alleyways represents another transitional agroforestry management option that is particularly suitable for converting large areas of cropland to forest. However, many land managers are reluctant to adopt these progressive methods of afforestation because of (1) an erroneous (in our opinion) perception that the tree species commonly used in agroforestry are not beneficial to wildlife, (2) continued belief that light-seeded species will naturally colonize afforested sites, and (3) lack of resources to ensure adequate weed control for newly established trees. As a compromise step that could provide limited vertical development within sites afforested using traditional methods, we supplemented oak-dominated plantings on bottomland sites with a series of systematically distributed patches of fast-growing trees.

Through the addition of small patches (100 m^2) of eastern cottonwood (*Populus deltoides*) and American sycamore (*Platanus occidentalis*) we sought to promote more rapid development of vertical forest structure and more quickly provide elevated sites for avian perches and nest platforms. We predict that providing rapid vertical structure for perching and breeding birds will increase the recruitment of woody species that use birds as vectors for seed dissemination and promote more rapid colonization of afforested sites by forest birds.

Within this paper, we assess the survival and development of supplemental planted cottonwood and sycamore after their first and second growing seasons. Additionally, we assessed the effect of fertilization, four methods of weed control applied at planting, and tree shelters on tree survival and development.

METHODS

Our study sites were agricultural fields, within the Mississippi Valley and adjacent bottoms, scheduled to be afforested during winter of 1997-98 or 1998-99. All study sites formerly supported bottomland hardwood forests. Each site was planted predominately to oak following traditional afforestation practices of the U.S. Fish and Wildlife Service and USDA Natural Resources Conservation Service. However, because restoration philosophies differed among land managers and because of different soil and hydrology, additional species were planted on some sites and included sweet pecan (*Carya illinoensis*), baldcypress (*Taxodium distichum*), persimmon (*Diospyros virginiana*), or green ash (*Fraxinus*

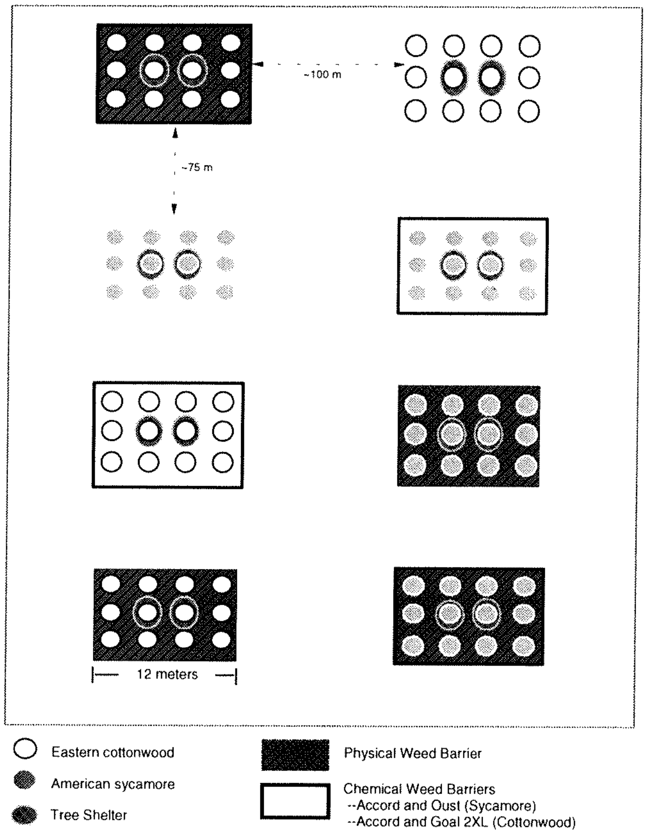


Figure 2—General distribution of 8 randomly assigned treatments (2 tree species x 4 weed control methods) applied to afforested study sites to assess the effect of small patches of fast-growing trees within oak dominated plantings.

pennsylvanica). We planted supplemental tree patches on a total of 40 sites (21 during 1998 and 19 during 1999; figure 1). Sites were disked or mowed before afforestation.

On all treated sites, we randomly applied different treatments to 8 systematically distributed patches using a 2 x 4 factorial design (2 tree species x 4 weed control methods). Our objective was to apply these treatments to patches that were at least 50 m from field edges and 100 m apart (figure 2). However, restrictions imposed by field size and dimensions often reduced between patch distance: the minimum distance between patches was 60 m.

Within each of the 8 treatment patches, we planted 12 trees in a 3-tree by 4-tree grid (figure 2). Trees were 4m apart within this planting grid. Eastern cottonwood was planted in 4 of the 8 patches whereas the other 4 patches were planted with American sycamore. These species were selected because they are often found on bottomland sites during early-succession, and because their use in agroforestry within the Mississippi Alluvial Valley made planting stock readily available. Planting stock was obtained from commercial pulpwood producers (Crown Vantage and Westvaco). We planted 30 centimeter (Crown Vantage) and 45 centimeter (Westvaco) stem cuttings of eastern cottonwood and 1-year-old, bare-root seedlings (Westvaco) of American sycamore. Sycamore seedlings were planted to the root collar as they were growing in the seedbed. All cottonwood stem cuttings planted on a site were from the same source (Crown Vantage or Westvaco) and were vertically inserted into the ground such that 1 to 3 inches were emergent with dormant buds facing up.

Because survival of these fast-growing species is likely enhanced when competition from weeds is reduced (Krinard and Kennedy 1987), we compared the effect of 4 different levels of weed protection. The 4 weed control treatments were: (1) no weed control, (2) physical weed barriers using commercially available wood fiber mats (RTI Mulch Mats, Reforestation Technologies International) or landscape fabric weed barriers (VisPore® Tree Mats, Treessentials Company), (3) single application chemical weed control at planting following practices used and recommended by industrial pulpwood producers, and (4) combined physical and chemical weed control.

On 24 afforested sites (19 during 1997-98 and 5 during 1998-99) we used both wood fiber and landscape fabric weed barriers. Within the patches that received physical weed control or both physical and chemical weed control on these 24 sites, we protected one-half the trees (6 trees) using wood fiber mats and the other half were protected using landscape fabric barriers. We used only landscape fabric barriers on the remaining 16 afforested sites.

Chemical weed control for cottonwood consisted of a single spray at planting of a glyphosate contact herbicide [Accord®] applied at a rate of 64 ounces/acre and a pre-emergent herbicide [Goal 2XL®]) applied at a rate of 64 ounces/acre. A similar dual herbicide treatment was applied to sycamore patches but the pre-emergent herbicide was Oust® applied at a rate of 4 ounces/acre. Pre-emergent herbicides differed between treatments because of industry recommendations and label restrictions. Herbicides were applied only to the vicinity of the planted patches and a small (~ 4 m) buffer. This application resulted in only about 0.1 ha per site treated with herbicide.

Because our objective was to achieve rapid vertical growth of planted trees, we fertilized all supplemental trees on 23 randomly selected sites. On these sites, we buried a 10 g fertilizer packet (18-6-6) or 10 g fertilizer tablet (20-10-5) adjacent to each planted tree.

Additionally, during 1998-99, we attempted to further enhance growth and survival by placing 1-m-tall (3-ft) Supertube® tree shelters (Treessentials Company) around 2 trees within each supplemental patch of trees. The lower edge of each tree shelter was below ground level and they were held upright by 1.2 m tall bamboo stakes.

We assessed survival and development of supplemental trees after 1 and 2 growing seasons. During these assessments, we classified each tree as alive or dead. For each live tree, we measured basal diameter to the nearest

Table 1—Survival (percent), height (centimeters), and basal diameter (millimeters) of American sycamore (*Platanus occidentalis*) and eastern cottonwood (*Populus deltoides*) planted in supplemental patches on afforested bottomlands during 1998-1999 and 1999-2000

Survival or size	Cottonwood	Sycamore
1st Year Survival	24.8 ± 4.6	47.0 ± 4.7
1st Year Height	83.0 ± 2.4	74.7 ± 1.1
1st Year Basal Diameter	14.4 ± 0.3	11.7 ± 0.1
2nd Year Survival of trees alive after 1 year	52.0 ± 6.8	76.9 ± 4.4
2nd Year Height	112.7 ± 3.3	109.2 ± 1.6
2nd Year Basal Diameter	21.8 ± 0.5	16.9 ± 0.3
Survival of re-planted trees	9.1 ± 2.6	35.8 ± 5.8
Survival of all trees after 2 growing seasons	19.0 ± 4.0	44.3 ± 5.3

millimeter and tree height (highest live bud) to the nearest centimeter.

We replanted tree mortalities using subjective criteria within which we attempted to ensure >1 live tree within each supplemental patch within the limitations of available planting stock. Survival of replanted trees was assessed after 1 year (i.e., after the second growing season for the original plantings) but data were maintained separate from data on our original plantings.

ANALYSIS

Mean percent tree survival, mean tree height, and mean basal diameter were compared between fertilizer treatments and among the 8 species-weed control treatments using a split plot analysis of variance (ANOVA). The 40 planted fields were the experimental units for comparing fertilizer treatments (WHOLE PLOTS) whereas the 8 patches of supplemental trees (SPLIT PLOTS) within each field were the experimental units for comparing species and weed treatments (2 species x 4 weed treatments x 40 sites = 320 experimental units). Individual trees within each planted patch were sub-sample units within these experimental units. Thus mean height, mean diameter, and proportion of trees surviving within each patch were the statistics compared. We applied an angular transformation to proportion data before subjecting to ANOVA.

We wrote specific contrast statements within the context of the ANOVA to compare between tree species and among the weed control treatments within each tree species. We assessed the effect of weed control treatments within each of the 2 tree species by writing contrast statements to compare (1) no weed control vs. the mean of the 3 weed control treatments and (2) chemical weed control vs. physical weed barriers. Additional contrasts were made based on the results of these comparisons.

We used separate analyses to compare weed barrier types and tree shelters. To compare weed barrier types we used only data from the 96 patches where we applied both landscape fabric weed barriers and wood fiber mulch mats. Similarly, we used data only from sites where tree shelters were deployed to compare survival and height of trees with and without shelters. Because survival data were categorical, and because the few trees treated within any individual patch (6 trees for barriers, 2 trees for shelters) made computation of proportion survival estimates unreliable, we used logistic regression to compare survival between weed barrier types and between tree shelter treatments. Thus, we assumed weed barrier types and tree shelters were randomly assigned to individual trees. However, we compared tree heights between weed barrier types and between tree shelter treatments using ANOVA wherein barrier type and shelter treatment were SPLIT plots within each species-weed control treatment patch.

RESULTS

After two growing seasons, the mean number of surviving supplemental trees of the 96 originally planted was 26.6 ± 3.6 per site. Five sites had no surviving trees and five additional sites had <10 live trees. The maximum number of surviving trees on any site was 81. Two sites were

Table 2—Mean survival (percent), tree height (centimeters), and basal diameter (millimeters) of eastern cottonwood (*Populus deltoides*) subjected to no weed control (None), physical weed barriers (Physical), herbicide treatment of Accord and Goal 2XL (Chemical), or a combination of physical weed barrier and herbicide (Both) treatments when planted in supplemental patches on afforested bottomlands during 1998-1999 and 1999-2000. Second year survival is with respect to those trees that were alive after one growing season. Height and basal diameter are of live trees

Survival or Size	None	Physical	Chemical	Both
1st Year Survival	17.5 ± 4.5	29.6 ± 5.5	26.5 ± 4.8	25.6 ± 4.9
1st Year Height	66.5 ± 9.2	75.4 ± 8.0	71.2 ± 9.0	79.9 ± 8.8
1st Year Basal Diameter	12.2 ± 1.4	13.6 ± 1.3	12.6 ± 1.5	13.7 ± 1.2
2nd Year Survival	47.8 ± 10.3	64.5 ± 8.4	53.9 ± 8.4	54.4 ± 7.4
2nd Year Height	81.7 ± 12.9	85.0 ± 10.2	94.8 ± 10.5	103.2 ± 14.2
2nd Year Basal Diameter	18.2 ± 1.6	18.2 ± 1.3	18.5 ± 1.3	20.8 ± 1.5

Table 3—Mean survival (percent), tree height (centimeters), and basal diameter (millimeters) of American sycamore (*Platanus occidentalis*) subjected to no weed control (None), physical weed barriers (Physical), herbicide treatment of Accord and Goal 2XL (Chemical), or a combination of physical weed barrier and herbicide (Both) treatments when planted in supplemental patches on afforested bottomlands during 1998-1999 and 1999-2000. Second year survival is with respect to those trees that were alive after one growing season. Height and basal diameter are of live trees.

Survival or size	None	Physical	Chemical	Both
1st Year Survival	48.8 ± 6.4	64.2 ± 6.0	34.8 ± 5.6	40.2 ± 5.4
1t Year Height	69.2 ± 4.1	76.9 ± 4.4	62.3 ± 6.4	59.4 ± 3.9
1st Year Basal Diameter	9.9 ± 0.4	12.0 ± 0.4	10.5 ± 0.8	11.3 ± 0.5
2nd Year Survival	76.7 ± 6.6	87.7 ± 3.8	57.2 ± 8.3	78.7 ± 5.9
2nd Year Height	94.3 ± 8.0	108.9 ± 7.1	91.4 ± 8.1	98.0 ± 4.9
2nd Year Basal Diameter	13.8 ± 0.9	17.1 ± 1.0	14.5 ± 1.2	15.6 ± 0.9

considered complete failures after the first year and were not revisited after the second growing season.

Fertilizer

Application of fertilizer did not effect tree survival ($F_{1,38}$ = 2.01, P = 0.16), tree height ($F_{1,38}$ = 1.01, P = 0.32), or tree basal diameter ($F_{1,38}$ = 1.84, P = 0.18) after the first growing season. This effect of fertilizer application was consistent among the 8 factorial treatments with regard to tree survival ($F_{7,266}$ = 0.77, P = 0.61), tree height ($F_{7,214}$ = 1.02, P = 0.42), and tree basal diameter ($F_{7,214}$ = 1.64, P = 0.13). The mean proportion of surviving trees after the first growing season was 0.43 ± 0.02 (x ± SE) when unfertilized and 0.31 ± 0.02 when fertilized. Tree height, however, was 60.9 ± 3.3 centimeter without fertilizer and 70.3 ± 2.9 centimeter with fertilizer. Similarly, tree basal diameter was 10.6 ± 0.5 millimeter without fertilizer and 12.0 ± 0.5 with fertilizer. Although not statistically significant, the greater height and basal diameter of fertilized trees suggested that fertilization was having a biological effect. If so, this effect was not accentuated during the second growing season. Neither tree height ($F_{7,151}$ = 0.58, P = 0.45) nor tree basal diameter ($F_{7,151}$ = 0.01, P = 0.93) differed between fertilizer treatments after 2 growing seasons.

Tree Species

We found significant differences in survival between tree species ($F_{1,266}$ = 62.7, P < 0.01) with 0.47 ± 0.05 American sycamore and 0.25 ± 0.05 eastern cottonwood surviving after the first growing season (table 1). Of the trees that survived the first growing season, 0.77 ± 0.04 of the sycamore remained alive after 2 growing seasons whereas only 0.52 ± 0.07 of the cottonwood survived the second growing season (table 1). Survival of 331 replanted sycamores (0.36 ± 0.06) was markedly greater than survival of 587 replanted cottonwoods (0.09 ± 0.03) (table 1). After two growing seasons, a total of 741 sycamores and 323 cottonwoods remained alive within supplemental patches.

Despite differences in survival between tree species, mean tree height did not differ between species after either the first ($F_{1,163}$ = 0.08, P = 0.78) or second ($F_{1,151}$ = 3.70, P = 0.06) growing season (table 1). However, cottonwood had greater basal diameters than did sycamore after the first ($F_{1,163}$ = 3.96, P = 0.03) and second ($F_{1,151}$ = 15.90, P < 0.01) growing seasons (table 1). Mean tree heights increased for both species between the first and second growing seasons (table 1). However, the maximum tree height attained by any tree of 3.0 meters after 1 growing season did not increase after the second growing season (3.0 meters).

Weed Control Treatments

Weed control near cottonwood (table 2) had a positive effect on their first year survival ($F_{1,266}$ = 6.57, P = 0.01) but did not effect mean tree height ($F_{1,163}$ = 2.40, P = 0.12) or mean basal diameter ($F_{1,163}$ = 0.99, P = 0.32). Similarly, second year survival of cottonwood (table 2) was greater with weed control then without weed control ($F_{1,266}$ = 5.12, P = 0.02) but weed control did not influence second year height ($F_{1,151}$ = 0.76, P = 0.39) or diameter ($F_{1,151}$ = 0.33, P = 0.56). Physical and chemical weed control afforded similar survival to cottonwood ($F_{1,266}$ = 0.58, P = 0.45) and resulted in similar heights ($F_{1,163}$ = 0.32, P = 0.57) and basal diameters ($F_{1,163}$ = 0.39, P = 0.53). Further, we detected no synergistic effect of the combination of chemical and physical weed protection on first year survival ($F_{1,266}$ = 0.23, P = 0.63).

For sycamore, the mean survival of patches with weed control (table 3) did not differ from survival of untreated controls after the first growing season ($F_{1,266}$ = 0.35, P = 0.55) nor after the second growing season ($F_{1,266}$ = 0.01, P = 0.91). However, this apparent lack of benefit from weed control was the indirect result of extreme differences in survival between physical weed barriers and chemical weed control (($F_{1,266}$ = 27.03, P < 0.01). Indeed, treatments that employed chemical weed control on sycamore significantly increased tree mortality over treatments where no herbicide was used ($F_{1,266}$ = 22.69, P < 0.01). In contrast, physical weed barriers increased tree survival compared to untreated controls ($F_{1,266} = 6.97$, $P < 0.01$).

For surviving sycamore, neither height ($F_{1,163} = 0.06$, $P = 0.80$) nor basal diameter ($F_{1,163} = 3.39$, $P = 0.07$) differed between the mean of all weed control treatments and the untreated control (table 3). However, in addition to limiting survival, chemical weed control reduced tree height (table 3) compared with patches of sycamore where no chemical was applied.

Weed Barrier Type

Tree survival was similar ($x^2 = 0.34$, $P = 0.56$) for trees protected by wood fiber mulch mats (44 percent) and for trees protected by landscape fabric weed barriers (42 percent). Similarly, mean tree height did not differ ($F_{1,54} = 0.73$, $P = 0.40$) between trees protected with wood fiber mats (68.3 ± 3.5 centimeters) and those protected by landscape fabric barriers (67.5 ± 3.9 centimeters).

Tree Shelters

Unexpectedly, survival of trees protected with tree shelters was significantly decreased ($x^2 = 105.55$, $P < 0.01$) by the addition of tree shelters. Only 26 percent of trees in shelters survived compared to 33 percent of trees that were not protected. Moreover, for those trees that did survive the first growing season, protection within tree shelters did not result in a significant increase in height over unprotected trees ($F_{1,48} = 0.31$, $P = 0.57$). After one growing season, the mean height of trees protected by shelters was 85.8 ± 5.8 centimeters whereas mean height of unprotected trees was 76.6 ± 4.1 centimeters.

DISCUSSION

Drought conditions prevailed during the growing season of the 3 years of this study. Long-term average rainfall for April-September in the Mississippi Alluvial Valley at Baton Rouge, LA is 82 centimeters. During our study, rainfall for this 6-month period was 58, 59, and 43 centimeters in 1998, 1999, and 2000, respectively. Physical weed barriers not only limited competition with weeds for moisture but also helped to reduce moisture loss to the atmosphere. However, even with weed protection, survival of supplemental trees, especially cottonwood was below our expectations.

On sites where survival was adequate, vertical development of both species did meet our expectations. In particular, cottonwood on several sites approached 3 m (10 ft) in height after the first growing season. Unfortunately, these were generally the only vertical substrates within these fields and thus, they were used extensively by white-tailed deer (*Odocolyis virginiana*) for browsing and more detrimentally as rubs for their antlers. Rubbing against these saplings invariably removed the cambium and thereby girdled the trees. Thus, during the next year, shoots developed from below the girdled area (usually about 1 meter from the ground). In addition to starting re-growth far below the previous terminal bud, girdling produced multiple competing stems. Because multiple stems compete for resources, vertical development of any single stem was reduced. Thus, our expectation of greatly increased vertical development during the second growing season was not realized.

Because sycamores tended to be smaller and developed many more lateral branches during their first growing season, deer rubbing of sycamore was not a significant problem after the first growing season. However, after 2 growing seasons, sycamores were incurring the same damage from deer rubbing that cottonwoods previously received. Furthermore, it appears that girdling of stems by deer will continue to be a recurring problem during tree dormancy.

The effect of chemical weed control on sycamore survival varied among sites but complete mortality of all trees and herbaceous vegetation within patches treated with Oust was not uncommon. We recalibrated spray equipment, verified application rate prior to planting, and took care to avoid spraying directly on planted seedlings during the second year of our study but increased mortality of sycamore within treated patches persisted. Soil conditions, particularly soil PH, likely contributed to the excessive mortality of sycamore associated with herbicide treatment.

Although we had hoped for greater survival of supplemental trees, we believe that the >10 trees that survived on 30 of our 40 study sites will be adequate to assess the effect of this technique on woody species diversity and avian colonization. An additional set-back was the small increase in vertical development after the first growing season. However, surviving trees likely have established root systems and substantial increased growth is likely during the next 3 years. As we do not plan to evaluate woody species diversity or bird response until 5 or 6 years after establishment, this time frame should be sufficient to provide supplemental trees that are well above the herbaceous vegetation and much taller that the trees planted via traditional afforestation methods. Indeed, observations by the author (DJT) indicate that supplemental patches are obvious anomalies within these otherwise homogeneous fields. Additionally, several bird nests, including at least one shrub nesting species (Orchard Oriole [*Icterus spurius*]), were built in supplemental trees during their second growing season. Therefore, we are hopeful that provision of these few supplemental patches of fast-growing trees within the context of large afforested sites will attract forest birds and ultimately will yield a more species rich forest at maturity.

RECOMMENDATIONS

When extending this concept from research to operational afforestation practice, we recommend increasing the number of species that are candidates for placement in small patches. Additional species that could be planted in supplemental patches include: honey locust (*Gleditsia triacanthos*), yellow poplar (*Liriodendron tulipifera*), sweetgum (*Liquidambar styraciflua*), or where non-native species are acceptable, royal paulownia (*Paulownia tomentosa*). Because we planted eastern cottonwood and American sycamore on all study sites, we made no attempt to ensure tree species compatibility with soil type or hydrology. However, planting only species that are compatible with site conditions should increase tree survival.

To increase the likelihood that some trees will survive within each supplemental patch, we recommend planting 2 or more tree species within each patch. Further, we recommend providing protection from weed competition through use of weed barriers. Planting more than 12 trees within a patch, for example 18 or 24 trees, increases the probability that at least some of these trees will be overlooked by deer and will exhibit substantial height increases between years.

ACKNOWLEDGMENTS

We thank Reforestation Technologies, International and Treessentials Company for providing physical weed barriers used in this study. Jim Baer (Westvaco) provided seedlings of American Sycamore and stem cuttings of eastern cottonwood. Jeff Portwood (Crown Vantage) provided cottonwood stem cuttings and Goal 2XL herbicide. Fran Henze (DuPont Agricultural Products) provided Oust herbicide. Additionally, we are grateful to Ray Aycock, Clyde Stewart, Jerome Ford, Ramsey Russell, Bill Alexander, Eric Johnson, Glenn Miller, Greg Harper, Dennis Sharpe, Kelby Ouchley, and Jon Wessman for coordination and access to sites on National Wildlife Refuges under the management of the U.S. Fish and Wildlife Service. We thank Robert Smith (Tennessee Wildlife Resources Agency) and Kenny Ribbeck (Louisiana Department of Wildlife and Fisheries) for providing access to sites on state Wildlife Management Areas. Finally, we are especially grateful to private landowners Allen Byrd, Allen Grittman, Norman Haigh, Dwaine Meyers, John Miller, Jack Taunton, and Robert Waits for granting access to their property.

REFERENCES

Allen, James A. 1990. Establishment of bottomland oak plantations on the Yazoo National Wildlife Refuge Complex. Southern Journal of Applied Forestry 14:206-210.

Allen, James A. 1997. Bottomland hardwood restoration and the issue of woody species diversity. Restoration Ecology 5: 125-134.

Creasman, Lisa; Craig, Nancy J.; Swan, Mark. 1992. The forested wetlands of the Mississippi River: an ecosystem in crisis. The Nature Conservancy of Louisiana, Baton Rouge, Louisiana 12 p.

Ezell, Andrew W. 1994. Importance of early season competition control in establishing eastern cottonwood (*Populus deltoides*) plantations. In: Edwards, M.B., comp. Proceedings of the Eighth biennial southern silvicultural research conference; 1994 November 1-3, Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 94-97.

Hodges, John D. 1997. Development and ecology of bottomland hardwood sites. Forest Ecology and Management 90:117-125.

Kennedy, Harvey E., Jr.; Gregory J. Nowacki. 1997. An old-growth definition for seasonally wet oak-hardwood woodlands. U.S.D.A. Forest Service, Southern Research Station, General Technical Report SRS-8, Asheville, North Carolina.

King, Sammy L.; Keeland, Bob D. 1999. A survey and evaluation of reforestation of the lower Mississippi River alluvial valley. Restoration Ecology 7: 348-359.

Knutson, Melinda G.; Klaas, Erv E. 1998. Floodplain forest loss and changes in forest community composition and structure in the upper Mississippi River: A wildlife habitat at risk. Natural Areas Journal 18:138-150.

Krinard, Roger M.; Kennedy, Harvey E., Jr. 1987. Planted hardwood development on clay soil without weed control through 16 years. U.S.D.A. Forest Service, Southern Forest Experiment Station, Research Note SO-343, 4 p.

Lower Mississippi Valley Joint Venture Management Board. 1990. Conserving waterfowl and wetlands: the Lower Mississippi Valley Joint Venture. North American Waterfowl Management Plan, Vicksburg, Mississippi 32 p.

Mueller, Allen J.; Twedt, Daniel J.; Loesch, Charles R. 2000. Development of management objectives for breeding birds in the Mississippi Alluvial Valley. In: Bonney, R.; Pashley, D. N.; Cooper, R. J.; Niles, L. eds. Strategies for bird conservation: the Partners in Flight planning process, Proceedings of the 3rd Partners in Flight workshop, 1-5 October 1995, Cape May, New Jersey. U.S. Forest Service, Rocky Mountain Research Station proceedings RMRS-P-16, Ogden, Utah. 12-17.

Noss, Reed F.; LaRoe, E. Ted; Scott, J. Michael. 1995. Endangered ecosystems of the United States: A preliminary assessment of loss and degradation. Biological Report 28, U.S. Department of Interior, National Biological Service, Washington, D.C. 58 p.

Stanturf, John A.; Schweitzer, Callie J.; Gardiner, Emile S. 1998. Afforestation of marginal agricultural land in the lower Mississippi River Alluvial Valley, U.S.A. Silva Fennica 32: 281-297.

Turner, R. E.; Forsythe, Steve W.; Craig, Nancy J. 1981. Bottomland hardwood forest land resources of the southeastern U.S. In: Clark, J. R.; Benforado, J. eds. Wetlands of Bottomland Hardwood Forests, Elsevier Science, Amsterdam, Holland. 13-38.

Twedt, Daniel J.; Loesch, Charles R. 1999. Forest area and distribution in the Mississippi Alluvial Valley: implications for breeding bird conservation. Journal of Biogeography 26: 1215-1224.

Twedt, Daniel J.; Portwood, Jeff. 1997. Bottomland hardwood reforestation for neotropical migratory birds: are we missing the forest for the trees? Wildlife Society Bulletin 25: 647-652.

Twedt, Daniel J.; Portwood, Jeff. In Press. Synergy of agroforestry and bottomland hardwood afforestation. Proceeding of the Sixth Conference on Agroforestry in North America. 12-16 June 1999. Hot Springs, Arkansas.

Wilson, R. Randy; Twedt, Daniel J. In Press. Bottomland Hardwood Establishment and Avian Colonization of Reforested Sites in the Mississippi Alluvial Valley. In: Fredrickson L (ed) Ecology and Management of Bottomland Hardwood Systems Symposium. 11-13 March 1999, Memphis, Tennessee.

BALDCYPRESS RESTORATION IN A SALTWATER DAMAGED AREA OF SOUTH CAROLINA

William H. Conner and Mehmet Ozalp[1]

Abstract—Baldcypress (*Taxodium distichum* (L.) Rich.) seed was collected in 1992 from nine different estuarine areas in the southeastern United States (Winyah Bay, SC, Ogeechee and Altmaha Rivers in GA, Loftin Creek, FL, Ochlockonee River FL, Mobile Bay, AL, West Pearl River, LA, Bayou LaBranche, LA, and Lake Chicot, LA) and planted in Clemson University's Hobcaw nursery in the spring of 1993. Germination ranged from a low of 16 percent for seed from FL to 58 percent for seed from NC. Seedlings were grown in the nursery for two growing seasons, lifted, and planted in an area killed by saltwater introduced by Hurricane Hugo's (1989) storm surge. Half of the seedlings were protected with tree shelters. Seedlings averaged 122 cm tall upon planting. Survival after 6 years was 99 percent. Height growth of seedlings in tree shelters was significantly higher than those not in tree shelters for each year except during year 3. Among the seed sources, seedlings from the Loftin Creek, FL source have shown greatest growth, with and without protection, for all growing seasons except the first year. After 6 years, average height of tree-shelter protected seedlings was 393 cm while the average height of non-protected seedlings was 281 cm. Tree-shelters increased early growth of seedlings, but once they emerged from the tree-shelter, growth differences between shelter and no-shelter treatments decreased and seems to be more related to the degree of deer herbivory experienced by unprotected seedlings.

INTRODUCTION

Low-lying coastal forested wetlands are particularly vulnerable to saltwater intrusion. Subsidence and sea level rise along the Northern Gulf of Mexico coast are causing increased flooding and saltwater intrusion into freshwater areas (Guntenspergen and others 1998). As a result, baldcypress (*Taxodium distichum* (L.) Rich.) and water tupelo (*Nyssa aquatica* L.) forests are being killed (Allen 1992, Krauss and others 2000, Pezeshki and others 1990). In addition, saltwater flooding caused by storm surges can significantly alter forest communities (Conner 1993, Gresham 1993, Williams 1993), and it may take years before the forest recovers (Conner 1995). Hurricanes are recognized as a normal part of the climatic regime, and natural ecosystems have developed morphologically and ecologically to aperiodic disturbances (Conner and others 1989, Pimm and others 1994). Hurricane wind damage is related to storm intensity, duration, forest structure, and soil conditions (Gresham and others 1991, Loope and others 1994). Forests generally recover quickly from wind damage. However, areas impacted by saltwater intrusion may require artificial regeneration in order to ensure adequate stocking. For example, when Hurricane Hugo came ashore north of Charleston, South Carolina on September 21, 1989, its storm surge was estimated to be as high as 3 m at Georgetown (Williams 1993). High winds and saltwater intrusion damaged an estimated 1.8 million ha (about $1 billion worth of timber) of South Carolina's forests (Hook and others 1991, Marsinko and others 1993).

Previous studies have shown some promising results indicating that baldcypress may tolerate some degree of salinity (0-8 ppt). Studies in Louisiana have shown that substantial intraspecific variation in salt tolerance exists within baldcypress populations (Allen 1994, Allen and others 1994, Krauss and others 1998, Pezeshki and others 1995). These studies were conducted under greenhouse conditions. The only field study that could be found was that of Krauss and others (2000), who planted baldcypress seedlings grown from seed collected in Louisiana, Mississippi, and Alabama. Survival and growth of baldcypress seedlings varied significantly among different salinity, hydrologic, and vegetative combinations in areas impacted by saltwater intrusion, and certain genotypes of baldcypress maintained greater height growth when planted in degraded wetlands.The major objective of this project was to determine if there are baldcypress populations in the southeastern United States that can survive and grow in saltwater damaged areas. A secondary objective was to determine whether or not using tree-shelters would increase survival and height growth of planted baldcypress seedlings.

MATERIALS AND METHODS

Hobcaw Forest is located 7 km southeast of Georgetown, SC (figure 1). A portion of the forest on the western edge of the property was damaged by saltwater intrusion when Hurricane Hugo's storm surge flooded the forest in September 1989. The impacted forest was originally dominated by baldcypress. The soil is a Hobcaw soil (fine-loamy, siliceous, thermic, Typic umraquults), very poorly drained, and moderately permeable with less than 2 percent slopes. Although high concentrations of salinity were found in the site up to 30 months after the hurricane (Williams 1993), there was no detectable salinity at the time of planting.

[1]Professor, Baruch Institute of Coastal Ecology and Forest Science, Box 596, Georgetown, SC 29442; Graduate Student, Clemson University, Department of Forest Resources, Clemson, SC 29634, respectively

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Height (cm) of baldcypress seedlings from 9 seed sources after 6 growing seasons in a South Carolina wetland forest damaged by Hurricane Hugo's storm surge. See text for explanation of seed source code names. Values in a row with unlike lower case letters are statistically different at an alpha level of 0.05

	Seed source								
Year	SC	ELA	SGA	WFL	SLA	EFL	CLA	NGA	AL
1995	142bc	147bc	150ab	137c	155a	151ab	142bc	144bc	142bc
1996	157c	164bc	168bc	164bc	175ab	181a	160bc	160bc	159bc
1997	172c	178bc	184bc	181bc	195ab	206a	181bc	182bc	176bc
1998	213c	227bc	229bc	228bc	251ab	273a	226bc	231bc	213c
1999	257c	290bc	277bc	288bc	316ab	345a	280bc	291bc	266c
2000	292c	330bc	323bc	347bc	369ab	407a	321bc	346bc	313bc

Baldcypress seeds were collected in November 1992 from seven estuarine areas subject to tidal influence (Winyah Bay, SC=SC; Ogeechee River, GA=NGA; Altamaha River, GA=SGA; Flint River, FL=EFL; Ochlockonee River FL=WFL; Mobile Bay, AL=AL; Bayou LaBranche, LA=SLA) and two freshwater areas (West Pearl River, LA=ELA; Lake Chicot, LA=CLA) (figure 1). Cones were collected from five trees at each site, air-dried, crushed to separate the seed, mixed with wet sand, and stored in plastic bags between 4 and 8 degrees C for 90 days.

After stratification, the seeds were planted in the Hobcaw nursery in the spring of 1993. After two growing seasons, the seedlings were lifted and prepared for planting by cutting all lateral roots off and cutting the tap root to approximately 23 cm (Conner and others 1999). The root-pruned seedlings were wrapped in moist peat and transported to the field where they were planted in an area killed by saltwater from Hurricane Hugo's storm surge. Tree shelters were placed on one half of the seedlings. Height growth was measured each year from 1995 to 2000. Statistical analyses of the data were done using a completely randomized design for repeated measurements with factorial arrangement between nine seed sources, two tree-shelter treatments, and six growing seasons.

RESULTS

Survival rates for all seed sources was high. After six growing seasons, survival for all trees was 99 percent. Only four trees died during the study and all of them were non-sheltered trees.

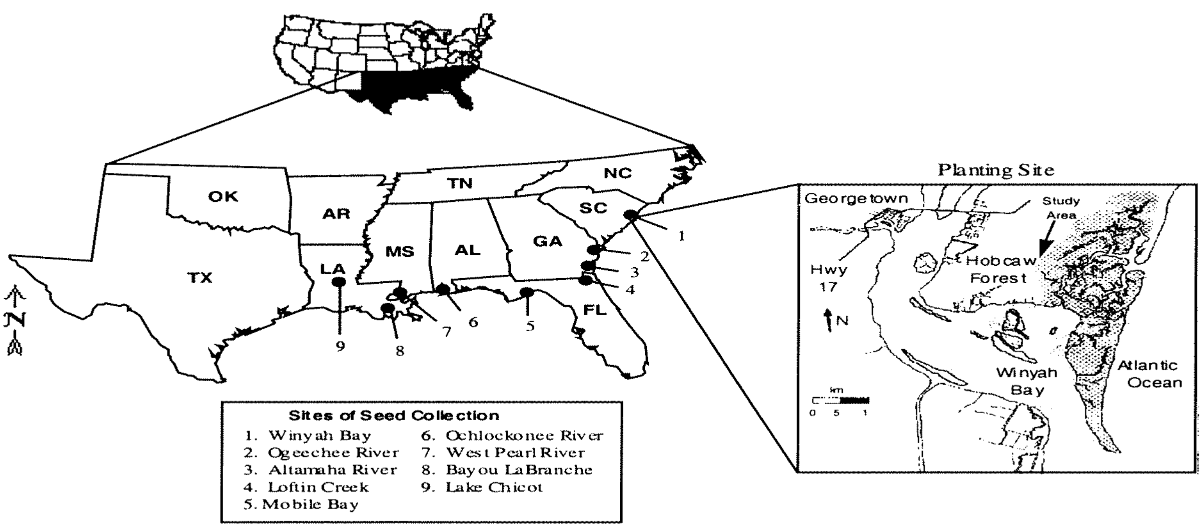


Figure 1—Map of the southern United States showing baldcypress seed collection sites and the South Carolina planting site.

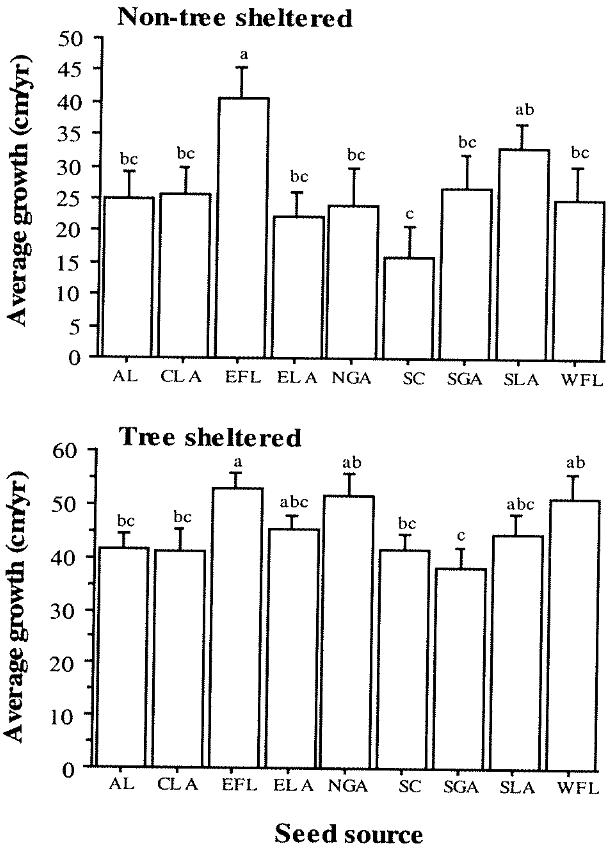


Figure 2—Average annual height growth (cm) of baldcypress seedlings planted in South Carolina with and without tree shelters. Error bars represent ±1 S.E.

After six growing seasons, average height of tree-shelter protected seedlings was 393 cm while the average height of non-protected seedlings was 281 cm. Growth of seedlings in tree shelters was significantly greater than for non-shelter seedlings except during the third growing season when both sheltered and non-sheltered seedlings increased by an average of about 17.8 cm/yr in height (figure 2). Overall, sheltered seedlings grew an average of 44.7 cm/yr while non-sheltered seedlings grew 25.4 cm/yr. All seedlings grew better after the third growing season. During the first three growing seasons, seedlings average growth was 20 cm/yr, but growth more than doubled for growing seasons 4 through 6.

Among seed sources, seedlings from east Florida (EFL) and south Louisiana (SLA) have shown the greatest growth by an average of 44.1 and 38.9 cm/yr, respectively. However, only EFL seedlings grew significantly better than all other seed sources (except those from SLA). The rest of the seed sources exhibited similar growth rates, and they were not significantly different from each other.

Growth differences were more readily noticeable in non-sheltered trees than in sheltered ones (figure 3). Growth of the non-sheltered EFL seedlings was significantly greater than all others sources other than SLA. In the sheltered seedlings, however, growth differences were less distinct. Although EFL seedlings had the highest average annual growth rate, they were not significantly greater than seedlings from ELA, NGA, SLA, or WFL.

Final heights of seedlings after six growing seasons in the field varied from a low of 292 cm for SC seedlings to a high of 407 cm for EFL seedlings (table 1). The EFL seedlings have grown the best in the planted site for five of the six years measured. During the first year, SLA seedlings were the tallest (155 cm), but not significantly so.

DISCUSSION

Coastal forests are increasingly being subjected to increased flooding and salinity levels. The impact is widespread and can be detrimental to these forests (Allen 1992, Conner 1994, Pezeshki and others 1990). Previous studies have examined species-level responses to salinity increases (Conner 1994, Conner and Askew 1994, Conner and others 1997, McLeod and others 1996) as well as family-level variations (Allen 1994, Allen and others 1994, Krauss and others 1998, Pezeshki and others 1995). Current research is aimed at finding and/or improving the tolerance of baldcypress for use in restoration projects in swamp forests damaged by saltwater intrusion (Allen and others 1994, Krauss and others 2000).

Baldcypress has demonstrated significant intraspecific variation in treatments as high as 8 ppt (Allen and others 1994), but beyond that, mortality is likely (Conner and others 1997). Interestingly, genotypes of baldcypress with the greatest amount of tolerance to salinity are not always found in brackish water seed sources. Krauss and others (2000) found that freshwater seed sources in their study were among the top performers under saline conditions in terms of height growth. The best performers in this study were from the more brackish areas, even though the site retained no measurable salinity.

Overall, all baldcypress seedlings from the nine sources in this study had high survival rate and good height growth in the saltwater damaged area. After six growing seasons, the area

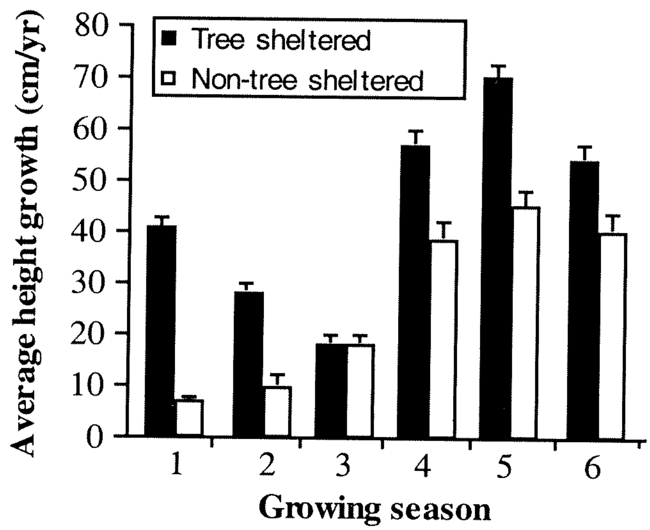


Figure 3—Average height growth of baldcypress seedlings with and without tree shelters by seed source. Error bars are ±1 S.E. and different lower case letters represent a significantly significant difference with an alpha level of 0.05

shows signs of success with respect to restoration efforts (i.e. planted seedlings are beginning to produce seed and young seedlings were observed in the area around the planted seedlings). These findings suggest that an adequate stocking of baldcypress in this saltwater storm surge damaged area has been accomplished through planting. In addition, protecting young seedlings with tree shelters improves early survival and growth and are recommended in areas where herbivory might be a problem.

ACKNOWLEDGMENTS

Funding was provided by the McIntire-Stennis Cooperative Forestry Research Program through Clemson University. In any such program of this duration, many people have helped with the field work. We especially want to thank Wayne Inabinette for his help in collecting seed, growing the seedlings, and assisting in planting and measuring the seedlings each year. We also thank Jeffery Vernon and Mike Gibson for field assistance. Belle W. Baruch Institute of Coastal Ecology and Forest Science Technical Contribution: 01-01.

REFERENCES

Allen, J.A. 1992. Cypress-tupelo swamp restoration in southern Louisiana. Restoration and Management Notes. 10: 188-189.

Allen, J.A. 1994. Intraspecific variation in the response of baldcypress (*Taxodium distichum*) to salinity. Baton Rouge, LA: Louisiana State University. Ph.D. dissertation. 183 p.

Allen, J.A.; Chambers, J.L.; McKinney, D. 1994. Intraspecific variation in the response of *Taxodium distichum* seedlings to salinity. Forest Ecology and Management. 70: 203-214.

Allen, J.A.; Pezeshki, S.R.; Chambers, J.L. 1996. Interaction of flooding and salinity stress on baldcypress (*Taxodium distichum*). Tree Physiology. 16: 307-313.

Conner, W.H. 1993. Artificial regeneration of baldcypress in three South Carolina forested wetland areas after Hurricane Hugo. In Brissette, John C., ed. Proceedings of the seventh biennial southern silvicultural research conference. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 185-188.

Conner, W.H. 1994. The effect of salinity and waterlogging on growth and survival of baldcypress and Chinese tallow seedlings. Journal of Coastal Research. 10(4): 1045-1049.

Conner, W.H. 1995. Woody plant regeneration in three South Carolina *Taxodium/Nyssa* stands following Hurricane Hugo. Ecological Engineering. 4: 277-287.

Conner, W.H. 1998. Impact of hurricanes on forests of the Atlantic and Gulf coasts. In Laderman, A.D., ed. Coastally restricted forests. New York, NY: Oxford University Press: 271-277.

Conner, W.H.; Askew, G.R. 1992. Response of baldcypress and loblolly pine seedlings to short-term saltwater flooding. Wetlands. 12(3): 230-233.

Conner, W.H.; Day, J.W., Jr.; Baumann, R.H.; Randall,J. 1989. Influence of hurricanes on coastal ecosystems along the northern Gulf of Mexico. Wetlands Ecology and Management. 1(1): 45-56.

Conner, W.H.; McLeod, K.W.; Carron, J.K. 1997. Flooding and salinity effects on growth and survival of four common forested wetland species. Wetlands Ecology and Management. 5: 99-109.

Conner, W. H.; K. W. McLeod; L. W. Inabinette [and others]. 1999. Successful planting of tree seedlings in wet areas. In Haywood, James D., ed. Proceedings of the tenth biennial southern silviculture research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 201-204

Gresham, C.A. 1993. Changes in baldcypress-swamp tupelo wetland soil chemistry caused by Hurricane Hugo induced saltwater inundation. In: Brissette, J.C., ed. Proceedings of the Seventh biennial southern silvicultural research conference; 1992 November 17-19, Mobile, AL. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 171-175.

Gresham, C.A.; Williams, T.M.; Lipscomb, D.J. 1991. Hurricane Hugo wind damage to southeastern U.S. coastal forest tree species. Biotropica. 23: 420-426.

Guntenspergen, G.R.; Vairin, B.A.; Burkett, V. 1998. Overview of coastal wetland global climate change research. In Gutenspergen, G.R.; Vairin, BA., eds. Vulnerability of coastal wetlands in the Southeastern United States: climate change research results, 1992-1997. Rep. USGS/BRD/BSR-1998-0002.089-97. Lafayette, LA: U.S. Department of Interior, U.S. Geological Survey, National Wetlands Research Center: 1-6.

Hook, D.D.; Buford, M.A.; Williams, T.M. 1991. Impact of Hurricane Hugo on the South Carolina coastal plain forest. Journal of Coastal Research. SI8: 291-300.

Krauss, K.W.; Chambers, J.L.; Allen, J.A. 1998. Salinity effects and differential germination of several half-sib families of baldcypress from different seed sources. New Forests. 15: 53-68.

Krauss, K.W.; Chambers, J.L.; Allen, J.A. [and others]. 2000. Growth and nutrition of baldcypress families planted under varying salinity regimes in Louisiana, USA. Journal of Coastal Research. 16(1): 153-163.

Loope, L.; Duever, M.; Herndon, A. [and others]. 1994. Hurricane impact on uplands and freshwater swamp forest. BioScience. 44: 238-246.

Marsinko, A.P.C.; Straka, T.J.; Baumann, J.L. 1993. Hurricane Hugo: a South Carolina update. Journal of Forestry. 91(9): 9-17.

McLeod, K.W.; McCarron, J.K.; Conner, W.H. 1996. Effects of inundation and salinity on photosynthesis and water relations of four southeastern coastal plain forest species. Wetlands Ecology and Management. 4(1): 31-42.

Pezeshki, S.R.; DeLaune, R.D.; Choi, H.S. 1995. Gas exchange and growth of baldcypress seedlings from selected U.S. Gulf coast populations: responses to elevated salinities. Canadian Journal of Forest Research. 25: 1409-1415.

Pezeshki, S.R.; DeLaune, R.D.; Patrick, W.H., JR. 1990. Flooding and saltwater intrusion: potential effects on survival and productivity of wetland forests along the U.S. Gulf Coast. Forest Ecology and Management. 33/34: 287-301.

Pimm, S.L.; Davis, G.E.; Loope, L. [and others]. 1994. Hurricane Andrew. BioScience. 44: 224-229.

Williams, T.M. 1993. Salt water movement within the water table aquifer following Hurricane Hugo. In: Brissette, J.C., ed. Proceedings of the Seventh biennial southern silvicultural research conference; 1992 November 17-19, Mobile, AL. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 177-184.

FIRST-YEAR EFFECTS OF PLASTIC TUBE SHELTERS, WIRE CAGES, AND FERTILIZATION ON PLANTED NUTTALL OAK SEEDLINGS

Troy S. Taylor and Michael S. Golden[1]

Abstract—A Study was implemented in western Alabama to compare the growth and survival of Nuttall oak (*Quercus nuttallii*) seedlings using plastic tube shelters, wire browse protection, fertilization, and control. A total of 324 Nuttall oaks were planted at a bottomland site in Greene County, Alabama. One-third of the seedlings were enclosed in 48-inch tall opaque plastic shelters. One-third of the seedlings were encircled with 48-inch tall wire fencing. The remaining seedlings were left as control. Fertilization tablets were supplied to one-half of all seedlings in each protection treatment. Black plastic mulch mats were utilized with all seedlings to help suppress herbaceous weeds. Initial measurements on seedling height and caliper growth were taken after planting in March 2000. First year growth measurements were taken in January 2001 and will be remeasured each winter thereafter. Plastic tube shelters stimulated both greater seedling height and diameter growth, compared to the wire cages and control treatments. Furthermore, fertilized seedlings exhibited significantly greater height growth and diameter growth compared to those without. Incidence of animal browse was significantly reduced by the presence of seedling protection devices.

INTRODUCTION

The reproductive characteristics of some of the most desirable timber and wildlife tree species, particularly the oaks, create special problems in successfully reproducing them after a harvest. Due to the thousands of mismanaged acres of bottomland forests that exist in Alabama from past high-grading, the oak component in many floodplains is scattered and of poor quality. High-quality sites that have been harvested commonly experience widespread oak regeneration failures. This is a critical problem because the oak species group is one of the major and more valued for the hardwood products industry (Aust and others 1984). The failures range from almost a complete loss of the oak component to a reduction in the relative dominance of oaks in the stand when compared to the composition of the pre-harvest stand (McGee and Loftis 1993). Sander and Graney (1993) report that although oaks are among the most abundant overstory species in many stands, they are often replaced in the reproduction that follows harvesting because of lack of adequate oak advance reproduction. Obtaining adequate oak regeneration is especially difficult on highly productive sites where understories are often well developed and dominated by shade-tolerant species. Often times advance oak regeneration is present in the understory but is outgrown and shaded out by competitor species.

At all sizes, oaks do not survive and grow well in dense, shaded conditions. Even in full sunlight, germinating seedlings allocate much of their growth to their root systems in the first few years and exhibit slow early height growth.

The paradox is that developing oak regeneration on productive sites has been difficult because stand prescriptions that encourage oak regeneration are the same conditions which favor the development of potentially faster growing competitor species (Kormanik and others 1995).

A multitude of plant species are able to germinate in the open-light conditions after a harvest on fertile floodplain soils. Many of these have the potential to restrict oak reproduction by creating conditions unfavorable to oaks. For high quality sites that are prone to natural regeneration failures, artificial regeneration can offer an alternative and viable solution. For artificial regeneration to be successful in highly productive river bottoms, some precautions need to be taken to ensure seedling survival and growth. There are two factors that need to be carefully considered when planting oak seedlings along river bottoms in the South: (1) the faster growing competitor species (vines, undesirable tree species, and herbaceous weeds), and (2) the high population density of white-tailed deer (*Odocoileus virginianus*) and, occasionally, of feral pigs as well. To address these issues it is necessary to protect seedlings from animal browse while at the same time creating and environment conducive to seedling height growth.

OJECTIVES

The objectives of this study are to determine whether there are differences in the growth, survival and animal browse intensity on planted Nuttall oak seedlings which have been subjected to various combinations of plastic tube shelters, wire cages, artificial mulch mats, and fertilizer tablets.

[1]Graduate Research Assistant; Associate Professor, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

METHODS/PROCEDURES

A recently cutover bottomland site was located north of Demopolis in Greene County, Alabama, in the floodplain of the Black Warrior River. Two planting areas were located at this site and their boundaries were marked. In the spring of 2000, a total of 324 Nuttall oaks were planted in holes dug using a portable gas-powered auger with a 6-inch bit. Three protection treatments were utilized—plastic tube shelters, wire cages, and control (no protection). One half of all seedlings of each protection type were fertilized at the time of planting with two 10-gram fertilization tablets (20-10-5). Approximately two cups of water were applied to each seedling one week after planting to aid in moisturizing the root systems due to a coincident drought. After planting, seedling height and caliper (at 1-inch above groundline diameter) were recorded. In January of 2001, seedling height and caliper were again recorded, and a measure of browse intensity was documented. At the end of the second growing season, seedling height and caliper will once again be measured, and a portion of seedlings within each protection and fertilization type will be excavated so that differences in root biomass can be examined.

EXPERIMENTAL DESIGN

1-0 Nuttall oak seedlings were obtained from E.A. Hauss Nursery in Atmore, AL, and stored in refrigerated coolers until planted in February, 2000. 162 seedling pairs were planted at the study site. Seedlings were planted at 20-ft by 20-ft spacing. Fertilizer application and seedling protection type were assigned randomly. All protection/treatment combinations were represented equally with 27 seedling pairs (54 total seedlings) for each of the six combinations of protection and treatment (plastic tube shelter, wire cage, control—with and without fertilizer application.

RESULTS

General Linear Model analyses were used to examine the relationships between treatment/protection type and first-season seedling height and groundline diameter growth. The first analysis was computed with height growth as the dependent variable and protection and fertilization class as independent variables. Results were significant: R-square = 0.5655, P = 0.0001 for protection and P = 0.0293 for fertilization. The interaction of protection type and fertilization was not significant for seedling height growth.

The second analysis was computed with first-season groundline diameter growth as the dependent variable and protection and fertilization class as the independent variables. Results were significant: R-square = 0.1431, P = 0.0009 for protection and P = 0.0010 for fertilization. The interaction of protection type and fertilization was not significant for seedling groundline diameter growth.

For seedling height growth, Duncan's Multiple Range Tests indicated significant differences among the means of protection type used. The use of plastic tube shelters stimulated greater height growth among seedlings than either the use of wire cages or control (table 1). There were no significant differences between seedling mean height growth of either wire cages or the control seedlings. Additionally, there were significant differences in seedling height growth for fertilizer application. Fertilized seedlings exhibited significantly greater

Table 1—Mean first-season height and diameter growth by protection type and fertilizer use. Protection types are as follows: S - plastic tube shelter, W - wire cage, C - control, no protection. Means followed by the same letter within the same column are not significantly different at the alpha = 0.05 level

Protection type	N	Mean height growth (cm)	Mean GLD growth (cm)
S	54	50.06a	4.51a
W	54	11.74b	3.69b
C	54	6.78b	3.28b
Fertilization application	**N**	**Mean height growth (cm)**	**Mean GLD growth (cm)**
yes	81	25.90a	4.27a
no	81	19.82b	3.38b

height growth in the first growing season than those unfertilized (figure 1).

For seedling groundline diameter growth, there were also significant differences among the means of protection types used. The use of plastic tube shelters stimulated greater groundline diameter growth than seedlings utilizing wire cages or the control group (table 1). There were no significant differences between the mean diameter growth of seedlings of the wire cages and control seedlings. Fertilized seedlings exhibited significantly greater groundline diameter growth in the first growing season than those unfertilized (figure 2).

Seedlings protected by either the opaque plastic tube shelters or the wire cages experienced very little damage due to browse, and then only if the terminal bud had protruded

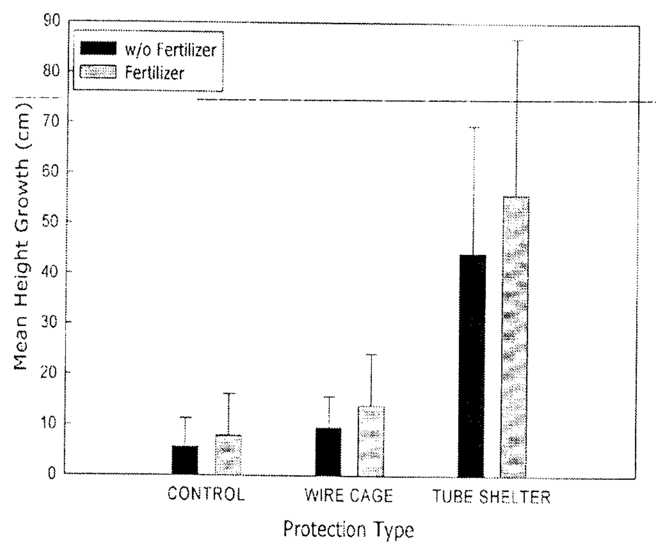


Figure 1—Mean height growth of Nuttall oak seedlings by protection type after one growing season.

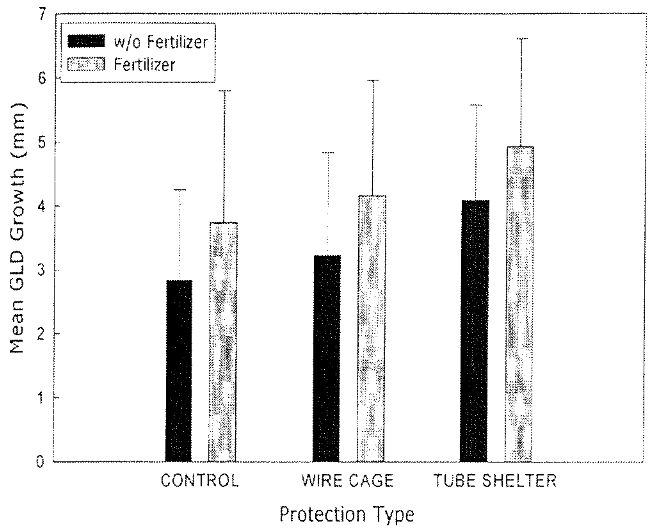


Figure 2—Mean GLD growth of Nuttall oak seedlings by protection type after one growing season.

through the top of the protection device. In contrast, 95.4 percent of the unprotected (control) seedlings were damaged by animal browse of some type and no longer retain their terminal buds. Of these, 28.2 percent of seedlings sustained browse heavy enough to cause extensive forking along the bole while 67.2 percent have only been slightly browsed (figure 3).

CONCLUSIONS

The 48-inch tall opaque plastic shelters stimulated both greater seedling height and groundline diameter growth compared to those enclosed in wire cages or those in the control treatments. Also, fertilized seedlings exhibited significantly greater seedling height growth and groundline diameter growth compared to those utilizing no fertilizer. Incidence of animal browse was significantly reduced by the presence of seedling protection devices.

ACKNOWLEDGMENTS

The authors would like to thank Mr. John Caldwell for providing access to the study site and donating monies to aid in the research effort. Thanks are also due to the Auburn University Graduate School for providing grants to cover travel expenses. Lastly, we would like to thank Capital Veneer Works for sponsoring the Robert Lewis Adams Fellowship for research in hardwood management.

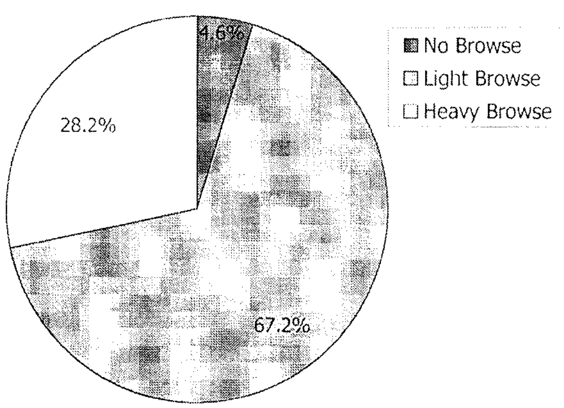


Figure 3—Browse incidence of unprotected (control) Nuttall oak seedlings after one growing season.

REFERENCES

Aust, W.M.; Hodges, J.D.; Johnson, R.L. 1985. The origin, growth, and development of natural, pure, even-aged stands of bottomland oak. In: Shoulders, E., ed., Third Biennial Southern Silvicultural Research Conference: Symposium proceedings; 1984 November 7-8; Atlanta, GA: Gen. Tech. Report SO-54. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 163-170.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L.; Zamock, S.J. 1995. Oak regeneration - why bigger is better. In: Landis, T.D. and Cregg, B., tech. coordinators, Forest and Conservation Nursery Associations, National proceedings; 1995 August 7-11; Kearny, NE. Gen. Tech. Report PNW-GTR-365. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 117-123.

McGee, C.E.; Loftis, D.L. 1993. Oak regeneration: a summary. In: Loftis, D.L. and McGee, C.E., eds., Oak regeneration: serious problems, practical recommendations: Symposium proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Report SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 316-319.

Sander, I.L.; Graney, D.L., 1993. Regenerating Oaks in the Central States. In: Loftis, D.L. and McGee, C.E., eds., Oak regeneration: serious problems, practical recommendations: Symposium proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Report SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 174-183.

EFFECTS OF LIGHT REGIMES ON 1-YEAR-OLD SWEETGUM AND WATER OAK SEEDLINGS

Yanfei Guo, Michael G. Shelton, and Hui Zhang[1]

Abstract—Light regimes vary significantly within small forest openings, ranging from full sunlight to total shade. This may affect establishment, early growth, and competitive status of hardwood seedlings. We used modified shadehouses to simulate light conditions within forest openings and to test the effects of daily photosynthetically active radiation and time of direct light exposure on growth of sweetgum (*Liquidambar styraciflua* L.) and water oak (*Quercus nigra* L.) seedlings. The study was a split-plot design in a completely randomized block layout with four replicates. The five light regime treatments representing the time of exposure to direct sunlight were NO, NOON, MORNING, AFTERNOON, and FULL. Greenhouse-raised sweetgum and water oak seedlings were planted in the treatment plots at a 0.3 x 0.3 meter spacing in early May 2000. Height, groundline diameter, and leaf surface area were determined at the end of the first growing season. Growth for both species generally increased with the amount of direct sunlight received. For treatments receiving some direct sunlight, sweetgum and water oak were the same height at the end of the growing season. However, sweetgum was 35 percent taller than water oak in the fully shaded treatment. For sweetgum, surface area of the average leaf was significantly larger in the fully shaded treatment than in other treatments, but no treatment differences occurred for surface area in water oak. Results suggest that sweetgum seedlings are more adaptive to low light levels than water oak seedlings during the first year of development.

INTRODUCTION

Oak seedlings are shade intolerant to intermediately intolerant and do not grow well under a closed forest canopy (Smith 1992). Once advanced oak reproduction is established, seedlings need adequate light to grow faster than competing vegetation (Minckler 1957, Bey 1964, Sander 1972, Johnson 1979). Light conditions under a canopy can be complex; direct and partial sunlight may reach seedlings during certain times of a day, but seedlings may be fully shaded at other times. A complex light regime with fluctuating periods of direct and indirect sunlight is difficult to mimic but may strongly affect seedling establishment and growth. Gardiner and Hodges (1998) used shadehouses to study the effect of various light conditions on cherrybark oak (*Quercus pagoda* Raf.) seedlings and found that height of 2-year-old seedlings was greatest with 27 and 53 percent of full sunlight. Groundline diameter showed a similar pattern, except that it was greater with 53 percent of full sunlight than with 27 percent. Similar results have been reported by others (Kolb and Steiner 1990a, 1990b; Gottschalk 1994).

Sweetgum (*Liquidambar styraciflua* L.) and water oak (*Q. nigra* L.) are widely distributed in the southeastern United States and have a very similar range (Kormanik 1990; Vozzo 1990). Both species are commercially important within the region. Sweetgum is a rapidly growing, pioneer species while water oak is a medium-sized rapidly growing species. Sweetgum and water oak are potentially major competitors because of their common occurrence. We hypothesized that timing and amount of photosynthetically active radiation (PAR) would affect the growth and characteristics of sweetgum and water oak seedlings. To test this hypothesis, we designed a non-traditional type of shadehouse to simulate the light conditions occurring within small forest openings. Each shadehouse had sections that had no shade cloth on top, which allowed direct sunlight to reach seedlings during different times of day. Applying the methods of Marquis (1965) and Satterlund (1983), we calculated the length of time seedlings were exposed to direct sunlight and tested the hypothesis that the timing and amount of direct sunlight and daily PAR affected seedling growth.

METHODS

The study site was located in Drew County, AR in the West Gulf Coastal Plain. The soil is an Amy silt loam (Typic Ochraquults). Site index for sweetgum and water oak is about 26 meters at 50 years. Before the study was established, the area was an open field, but native vegetation is classified as mixed pines and hardwoods (Larance and others 1976). Annual precipitation averages 134 centimeters, with most occurring in winter and early spring.

The study was a split-plot design in a completely randomized block layout with four replicates. The main plot was exposure to direct sunlight, and subplot was tree species. With the shadehouses oriented toward north, five light regimes were created based on when direct sunlight

[1]Assistant Professor, School of Forest Resources, University of Arkansas-Monticello, Monticello, AR 71656; Research Forester, Southern Research Station, Monticello, AR 71656; and former Graduate Research Assistant, School of Forest Resources, University of Arkansas-Monticello, Monticello, AR 71656, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

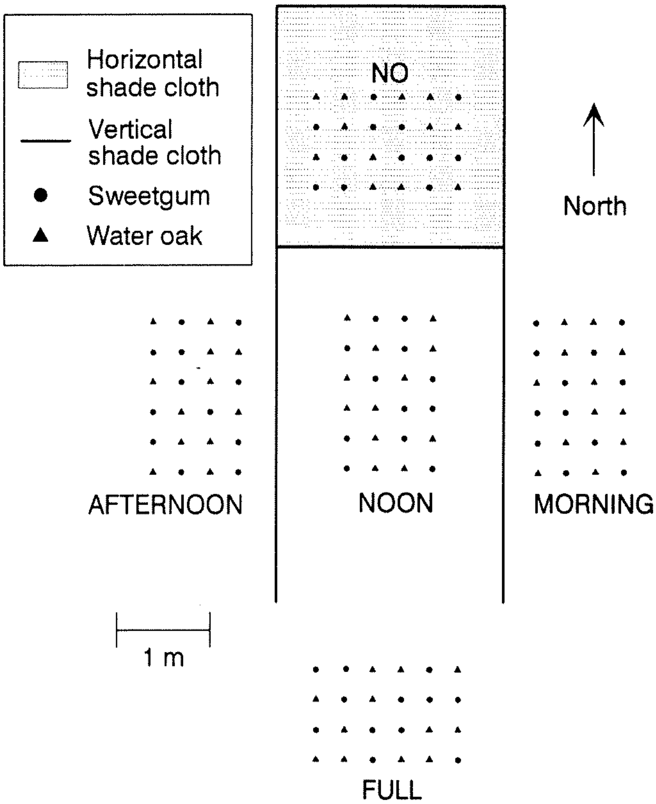


Figure 1—Layout of a modified shadehouse used to create different light regimes for sweetgum and water oak seedlings.

occurred: mostly in the morning (MORNING), around noon (NOON), mostly in the afternoon (AFTERNOON), all day (FULL), and at no time (NO). Shade for the MORNING and AFTERNOON treatments came from the vertical walls (2.4 m tall) of the NOON treatment (figure 1). All shade cloth provided 20 percent of full sunlight. The shadehouse for the NO treatment had shade cloth on the top and all sides except for the lower half of the north side. The NOON treatment only had vertically-oriented shade cloth on the north, east, and west side. The treatments were intended to represent the light conditions occurring within a small forest opening: FULL at the center of a large opening, NO at the south end, MORNING at the western edge, AFTERNOON at the eastern edge, and NOON at the center and northern edge of smaller openings.

Seeds from about 20 open-pollinated trees for each species were collected in Drew County, AR in November 1999, float tested, and stored in a refrigerator at 4 degrees Centigrade. Seeds were stratified for 30 days before germinating in a peat-vermiculite mixture under greenhouse conditions in mid-February. Seedlings were field planted during early May 2000.

Twelve seedlings of each species were planted in each plot with a 0.3 x 0.3 meter spacing in six rows by four columns or four rows by six columns for a total of 480 seedlings in the study. Two seedlings of each species were randomized within each row or column containing four seedlings. During the first month after the planting, we replaced dead seedlings with live seedlings of the same species. Weed-free cloth was used to prevent herbaceous plant competition within the beds. Herbaceous vegetation outside of the beds was periodically controlled with a foliar-applied herbicide. Seedling beds were irrigated to field capacity about weekly from July to September 2000 because of severe drought conditions.

A LI-190SA quantum sensor (LI-COR, Inc. Lincoln, NE) was installed in each treatment of one shadehouse. The calibrated sensors allowed determination of mean PAR for each treatment. PAR was automatically recorded by a LI-1000 data logger (LI-COR, Inc. Lincoln, NE) at a 15-minute interval for 2 days a week beginning in July and ending in early October 2000. The average PAR for each 15-minute interval was calculated for each treatment over the monitoring period, and total daily PAR was computed by adding all the measurements for the average day. Air temperature of one shadehouse was monitored by HOBO Pro Series temperature data loggers (Onset Computer Corporation, Pocasset, MA) throughout the growing season at 5-minute intervals. Temperature sensors were located 30 centimeters above the ground and were protected by white-plastic radiation shields. Soil moisture was monitored by Moisture Point probes (Gabel Corporation, Victoria, Canada) in each bed of all shadehouses. Soil moisture was determined about 7 days after irrigating to field capacity from July to early October 2000.

Seedling height and groundline diameter were measured in October 2000. Forty-eight fully developed leaves from each species and bed were randomly collected, and leaf area and dry weight were determined. Analysis of variance for a split-plot design was conducted on height, groundline diameter, leaf characteristics, and soil moisture using SAS procedure GLM (SAS 1990). Light regime treatments were main effects, and species or soil monitoring depth were subeffects. Replicates for height and diameter were the means for the 12 seedlings of each species in each bed of the four shadehouses, while replicates for leaf characteristics were the means of 48 leaves per species from each bed. Replicates for soil moisture were the means of eight measurements made at a specific depth for each bed from July to early October. Significance was accepted at α= 0.05.

RESULTS AND DISCUSSION

The light regimes affected when and how much direct sunlight the seedlings received, and this was reflected in the amount of PAR. The shadehouses created a 3.2-fold difference in PAR across all treatments, and mean daily value was as follows: NO (10), NOON (19), MORNING (27), AFTERNOON (28), and FULL (32 moles per square meter per day). Treatments also differed in mean duration of direct sunlight exposure at ground level from May through October: NO (0.0), NOON (3.4), AFTERNOON (8.5), MORNING (8.4), and FULL (13.0 hours per day).

Air temperature during the day reflected the exposure of beds to direct sunlight (figure 2). In the morning, only the MORNING and FULL treatments received direct sunlight, and this elevated air temperature by 1.0 degree Centigrade over shaded treatments. At noon, all treatments except the NO treatment were in direct sunlight, and air temperature was elevated by an average of 2.4 degrees Centigrade. In

Table 1—Effect of light regime on the mean properties of leaves of sweetgum and water oak seedlings at the end of the first growing season

Direct sunlight exposure	Weight (g/leaf)	Area (cm^2/leaf)	Specific leaf area (cm^2/g)
		---------------Sweetgum---------------	
NO	0.30	59	195
NOON	0.33	48	148
MORNING	0.31	39	125
AFTERNOON	0.31	39	126
FULL	0.35	36	105
		---------------Water oak---------------	
NO	0.11	14	136
NOON	0.14	17	122
MORNING	0.15	16	109
AFTERNOON	0.13	14	106
FULL	0.16	15	99

the afternoon, the FULL and AFTERNOON treatments were the only treatments in direct sunlight, and their temperature was 1.5 degrees Centigrade higher than the treatments in shade.

Water utilization was also affected by exposure to direct sunlight (figure 3). Approximately 7 days after watering to field capacity, volumetric moisture content of the soil was lowest for the FULL treatment and highest for the NO treatment for all monitored depths. Most of the water was apparently transpired because the weed-free cloth and mulch greatly reduced soil evaporation. The differences among light regime treatments and depths were significant for soil moisture (P<0.003) but their interaction was not (P=0.16).

There was no difference in seedling mortality among the treatments, which averaged less than 1 percent for both

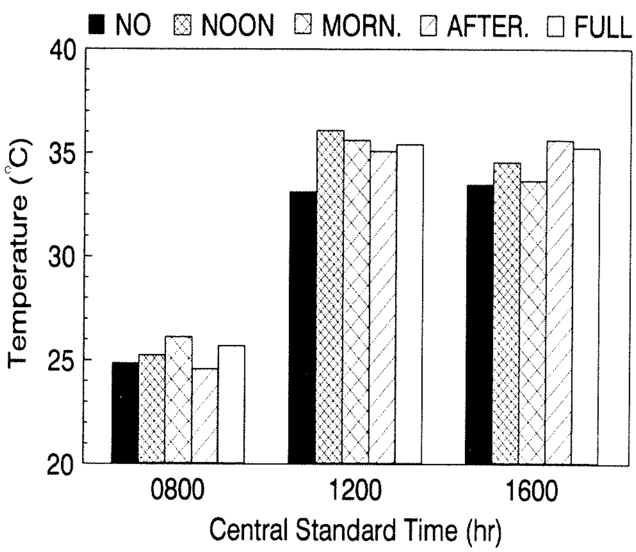


Figure 2—Effects of exposure to direct sunlight on mean air temperature in the morning, at noon, and in the afternoon from July through October.

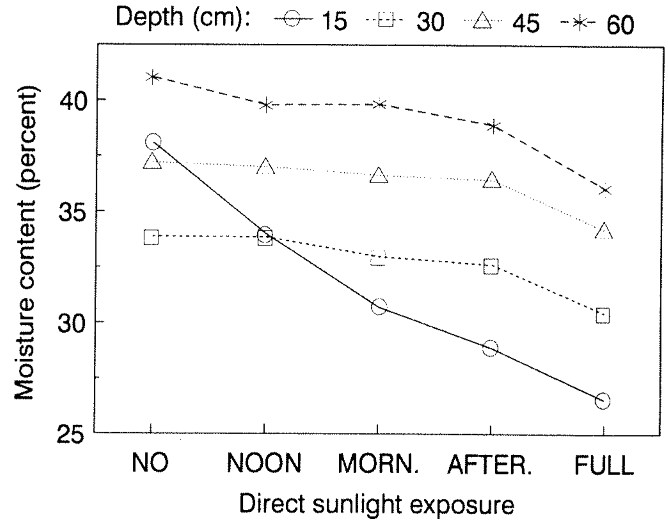


Figure 3—Effects of exposure to direct sunlight on the mean volumetric moisture content of the soil at four monitoring depths approximately 7 days after watering to field capacity from July to early October.

sweetgum and water oak after the termination of replanting. Light regime affected height and groundline diameter for both species (figure 4). There was no difference between the two species for height (P=0.34), but the species differed for diameter (P=0.0001). Light regime and species interacted significantly for height (P=0.03), but did not interact significantly for groundline diameter (P=0.38). Seedling height and groundline diameter of both sweetgum and water oak generally increased with

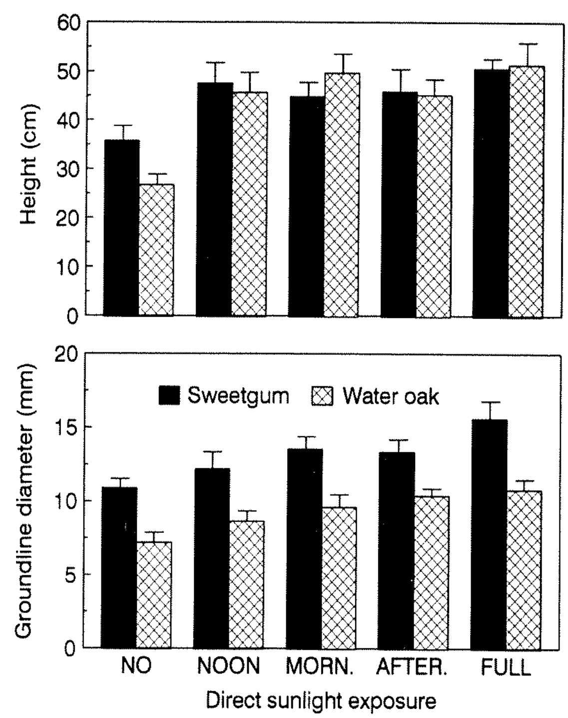


Figure 4—Effects of exposure to direct sunlight on mean height and groundline diameter (plus one standard error) of sweetgum and water oak seedlings at the end of the first growing season.

increasing exposure to direct sunlight. For both species, the most distinctive difference for height was between the NO treatment and the other treatments which received some direct sunlight exposure. With some direct sunlight, there was little difference between the height of sweetgum and water oak, but sweetgum was 35 percent taller than water oak for the NO treatment. Sweetgum consistently had larger groundline diameters than water oak. We observed that water oak would temporarily bend over because of its slender stem when leaves were wet. The difference in height and groundline diameter growth of sweetgum and water oak probably reflects some inherent difference in the early growth pattern of the two species.

Leaf morphology also reflected the differences in exposure to direct sunlight (table 1). For surface area, weight, and specific leaf area (SLA), significant differences occurred for both species and light regime treatments ($P<0.01$). The interaction of species and light regimes was significant for area and SLA ($P=0.0001$) but not for weight ($P=0.74$). The leaves of sweetgum were much larger than those of water oak, by an average of 2.2 times for weight and 2.9 times for area. The SLA of sweetgum and water oak was the same for the FULL treatment (about 100 square centimeters per gram), but the SLA of sweetgum exceeded that of water oak when direct sunlight exposure declined. For the NO treatment, the SLA of sweetgum exceeded that of water oak by 43 percent. Water oak appeared to be less adaptive to reduced exposure of direct sunlight than sweetgum.

CONCLUSION

Although light regime did not affect survival, seedlings exposed to full or partial direct sunlight had higher growth rates during the first growing season than seedlings that did not receive direct sunlight. Thus, the size of forest openings or overstory coverage will be important to provide adequate direct sunlight exposure for seedling development. By producing leaves with a higher SLA, sweetgum appeared to be more adaptive to increasing levels of shade than water oak. Thus, early results of our study suggest that high levels of sunlight are important for water oak to be competitive with sweetgum, especially in early height growth. Since the highest levels of shade occur along the southern edge of small forest openings, this is where water oak will be at a competitive disadvantage with sweetgum. The water-use efficiency was less for treatments receiving high levels of direct sunlight, and the results of our study may have been different had we not controlled competing herbaceous vegetation or provided supplemental water.

REFERENCES

Bey, C.F. 1964. Advanced oak reproduction grows fast after clearcutting. Journal of Forestry. 62: 339-340.

Gardiner, E.S.; Hodges, J.D. 1998. Growth and biomass distribution of cherrybark oak (*Quercus pagoda* Raf.) seedlings as influenced by light availability. Forest Ecology and Management. 108: 127-134.

Gottschalk, K.W. 1994. Shade, leaf growth and crown development of *Quercus rubra*, *Quercus velutina*, *Prunus serotina* and *Acer rubrum* seedlings. Tree Physiology. 14: 735-749.

Johnson, R.L. 1979. Adequate oak regeneration--a problem without a solution. In: Management and utilization of oak: Proceedings of the seventh annual hardwood symposium of the Hardwood Research Council; 1979 May; Cashiers, NC. Asheville, NC: Hardwood Research Council: 59-65.

Kolb, T.E.; Steiner, K.C. 1990a. Growth and biomass partitioning of northern red oak and yellow poplar seedlings: effects of shading and grass root competition. Forest Science. 36: 34-44.

Kolb, T.E.; Steiner, K.C. 1990b. Growth and biomass partitioning response of northern red oak genotypes to shading and grass root competition. Forest Science. 36: 293-303.

Kormanik, P.A. 1990. *Liquidambar styraciflua* L. Sweetgum. In: Burns, R.M., Honkala, B.H. (Tech. Coord.), Silvics of North America, Volume 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 400-405.

Larance, F.C.; Gill, H.V.; Fultz, C.L. 1976. Soil survey of Drew County, Arkansas. Washington, DC: U.S. Department of Agriculture Soil Conservation Service; Fayetteville, AR: Arkansas Agricultural Experiment Station. 86 p. + maps.

Marquis, D.M. 1965. Controlling light in small clearcuttings. Res. Pap. NE-39. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 16 p.

Minckler, L.S. 1957. Response of pole-sized white oak trees to release. Journal of Forestry. 55: 814-815.

Sander, I.L. 1972. Size of oak advance reproduction: key to growth following harvest cutting. Res. Pap. NC-79. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 6 p.

SAS Institute, Inc. 1990. SAS user's guide. Volume 2, version 6, 4th edition. Cary, NC: SAS Institute, Inc. 846 p.

Satterlund, D.R. 1983. Forest shadows: how much shelter in a shelterwood? Forest Ecology and Management. 5: 27-37.

Smith, D.W. 1992. Oak regeneration: the scope of the problem. In: Loftis, D.L.; McGee, C.E. (eds.). Oak regeneration: serious problem, practical recommendations. 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 40-53.

Vozzo, J.A. 1990. *Quercus nigra* L. Water oak. In: Burns, R.M.; Honkala, B.H. (Tech. Coord.), Silvics of North America, Volume 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 701-703.

Hardwood Natural Regeneration

Moderator:

WAYNE CLATTERBUCK
University of Tennessee

OAK REGENERATION USING THE TWO-AGE SYSTEM

Jeffrey W. Stringer[1]

Abstract—The two studies presented in this paper were completed in southeastern Kentucky and were designed to evaluate acorn production and development of advanced white oak reproduction from fully released white oak (*Quercus alba*) trees typical of reserve trees in the two age system. Twelve 2 acre 60- to 90-year-old white oak dominated stands were randomly assigned 1 of 3 treatments including an uncut treatment, and two cut treatments of 20 fully released canopy trees per acre, and 34 trees per acre. Acorn production from 11 to 15 years and regeneration accumulation, canopy cover and light regimes were monitored 15 years after treatment. Released trees produced significantly ($p < 0.01$) more acorns (1,424 grams per tree per year) compared to unreleased trees (689 grams per tree per year). Highly significant differences ($p < 0.001$) were found among treatments for cumulative white oak advanced regeneration density, height and densitometer readings. Strong relationships between densitometer readings and: PPFD; regeneration density; and regeneration height were found (R^2=ranging 0.743 to 0.974). The results of this study indicate that reserve white oak trees can provide for the recruitment of advanced oak regeneration and maintenance of light levels using easily applied crown densitometer readings can enhance the development of advanced regeneration required for the long-term maintenance of this species after future regenerative treatments.

INTRODUCTION

By definition the two age system maintains two distinct age classes throughout the majority of the rotation and is initiated by treatments which retain a limited number of canopy trees (reserve trees) along with a cohort of younger regenerating stems (Nyland 1996). Typically the two age stand is produced using a deferment cut where a limited number of reserve trees, occupying 10-30 ft^2 of basal area per acre, are selected from the overstory and retained for a second rotation while the remaining stems are removed (Stringer 1998). The number and distribution of the reserve trees must be such that as they produce little short- or long-term effect on regeneration and the development of the younger age class (Miller and Schuler 1995). Often times the stand, with the exception of the reserve trees, is subject to site preparation operations similar to clear cutting. This results in two distinct age classes, the older reserve trees and the younger regenerating cohort. While this system has been often termed shelterwood with reserves or irregular shelterwood the term shelterwood is misleading because the reserve trees are not intended to provide any sheltering effect to the regeneration.

This method has been used as an aesthetic alternative to clearcutting and as a means of potentially developing a limited number of large diameter high value sawtimber trees in a stand (Sims 1992; Smith and others 1989). The system also has structural and habitat advantages compared to clear cutting (Beck 1986; Miller and others 1995). Regardless of the objective, reserve trees in deferment cuts must be of proper vigor, landscape position, species, age, and potential tree grade so that they will survive and provide a viable product after two rotations. Not all stands and species can be managed using the two age system. Species which are relatively long lived and are commercially important make good candidates for reserve trees.

Besides the aesthetic and habitat values that two-aged stands have compared to clear cut stands they can be used to "life boat" species which do not have viable reproductive life forms at the time of cutting. A traditional clearcut essentially stops sexual reproduction in the stand for a substantial portion of the rotation and can limit the potential for the development of viable advanced regeneration. The reserve trees in the two age system provides for the potential for continued sexual reproduction in the stand and the ability to develop advanced regeneration which can be manipulated prior to the second regeneration cut. The maintenance of sexual reproduction throughout a rotation or a significant portion of it may be important for sporadic producers such as oak species. This paper presents the results of two studies conducted on the same study area. The first study was designed to determine acorn production from fully released small sawtimber white oak (*Quercus alba*) trees. The second study was designed to determine whether stands containing only a limited number of released white oak canopy trees could initiate the development of advanced regeneration.

[1]Associate Professor and Hardwood Silviculture Extension Specialist, Department of Forestry, University of Kentucky, Lexington, KY 40546-0073

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

METHODS

This paper reports both the acorn production between 12 and 15 years of fully released white oak trees and the 15 year cumulative development of new seedlings and advanced regeneration in stands retaining a limited number per acre of fully released canopy white oaks. The study site was located at Robinson Forest, the University of Kentucky research and demonstration forest located in Cumberland Plateau Physiographic Province in southeastern Kentucky. While this study was initiated as a growth and yield study for crop tree management of small sawtimber white oak stands (Stringer and others 1988) the full crown touching release and the relative numbers of crop trees in these stands (within the range recommended for two age reserve trees) provided an excellent opportunity for the determination of some of the regeneration dynamics associated with stands managed under a two age system. In 1983 twelve 2 acre 60- to 90-year-old white oak dominated stands were selected for study. In 1983 each stand was randomly assigned one of 3 treatments including an uncut treatment, a treatment leaving only 20 canopy trees per acre, and one leaving only 35 canopy trees per acre. The treatments were imposed by full crown touching release of selected canopy trees. These trees were of average dbh for co-dominant and dominant trees in these stands. One-half acre growth and yield plots were established in the middle of each treated stand. Trees > 2.54 cm dbh were tagged and survival and growth monitored and ten 1/100th acre regeneration plots were also randomly established in each growth and yield plot. In 1994, three reserve canopy trees were randomly selected in each growth and yield plot and 3 one meter square acorn traps (David and others 1998) were randomly placed under the crown of each tree. Acorns were collected from traps at two week intervals during the fall of 1994 through 1997. Total acorn mass was determined for each tree and pooled by treatment for analysis.

Final white oak regeneration measurements were taken during July 1997 and included the number and height of each white oak stem established after treatment. To provide a relative gauge of canopy light interception and the light environment at each regeneration plot a concave spherical crown densitometer™ (Forestry Suppliers, Inc. 24 quarter inch cross hairs) reading was taken at plot center. Data was recorded and is expressed in this paper as the number of cross-hairs where open sky was observed. At the same time a series of five photosynthetic photon flux density (PPFD) measures (μmol/meter²s PAR) were taken at a height above ground equal to the average height of the advanced regeneration (30 centimeter) at every other plot center using a quantum sensor (LI-COR, Inc.) and the values averaged by plot. All PPFD and densitometer readings were taken under clear sky conditions. White oak advanced regeneration data were pooled by treatment and subjected to statistical analysis using ANOVA and LSD(t) to determine treatment effects. Simple linear regression was used to establish the relationship between PPFD (dependent variable) and densitometer reading (independent variable) and advanced regeneration height (dependent variable) and densitometer reading (independent variable) pooled over all treatments. The Levenberg-Marquardt algorithm was used to establish best-fit coefficients of nonlinear functions for regeneration density (dependent) and densitometer reading (independent) pooled over all treatments.

Table 1—Density and height of *Quercus alba* advanced regeneration in two age stands[a]

	density (no./ha)	height (cm)	densitometer reading
uncut	227b	19.8b	5.72c
20 per acre	930a	35.0a	7.16a
35 per acre	450b	29.9a	6.47b

[a] Values with different letters are significantly different ($p < 0.01$) using ANOVA and LSD(t).

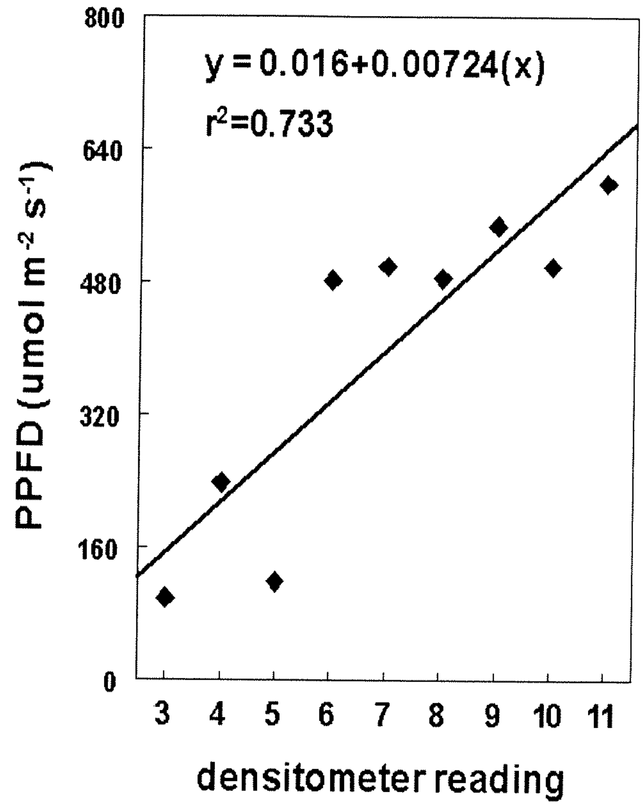


Figure 1—Data points represent average PPFD for each densitometer reading. The line represents a positive linear relationship ($y = 0.016 + 0.00724(x)$, R^2=0.733) between densitometer reading and PPFD.

RESULTS AND DISCUSSION

There was no significant difference ($p > 0.05$) among annual acorn yields of the 20 and 35 tree per acre treatments and data were pooled for comparison with the uncut treatment. Analysis of released treatments vs. uncut (unreleased) treatment showed a highly significant difference ($p = 0.008$) in acorn yield (as expressed on a per

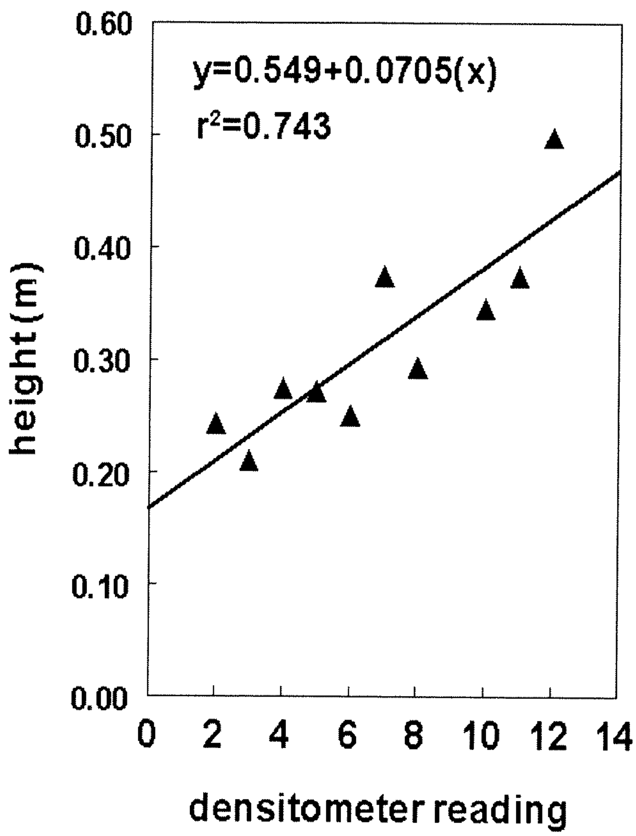


Figure 2—Data points represent average *Quercus alba* advanced regeneration stem density for each densitometer reading. The line represents an exponential relationship between densitometer reading and regeneration density (y = 43.615 + 22.373*exp(-x/-2.489), R^2=0.974).

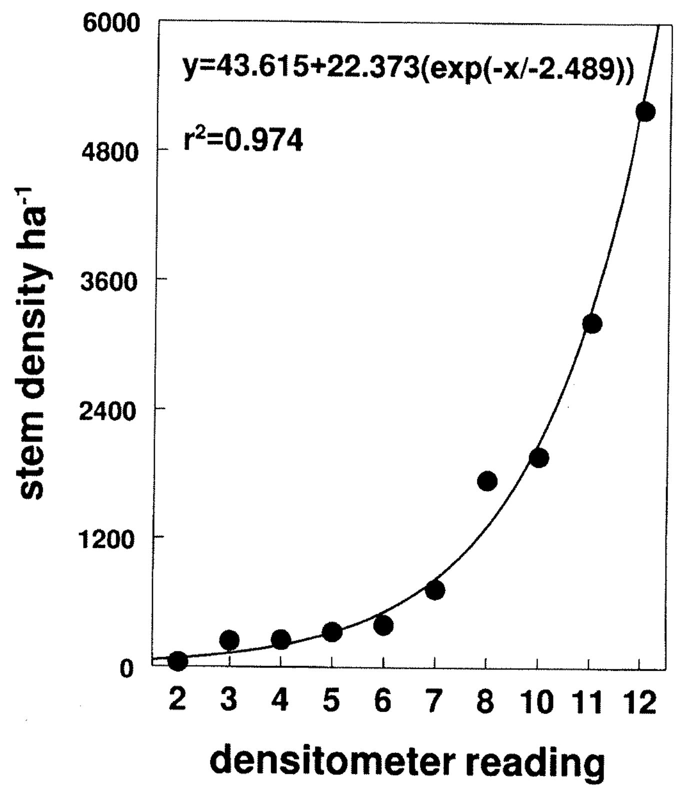


Figure 3—Data points represent average *Quercus alba* advanced regeneration height for each densitometer reading. The line represents a linear relationship between densitometer reading and regeneration height (y=0.549+0.0705(x), R^2=0.743).

tree basis). Released trees annually averaged 1,424 grams of acorns per tree compared to 689 grams per tree for unreleased trees. This indicates that fully released trees, typical of those that would be retained as reserve trees in deferment cuts in white oak dominated stands, have the capability of not only maintaining but improving acorn yield, a prerequisite for the development of advanced regeneration in two aged stands.

Highly significant differences ($p < 0.001$) were found among treatments for white oak advanced regeneration density, advanced regeneration height, and densitometer readings (table 1). The 20 reserve tree per acre treatment developed twice the number of regenerating white oak trees as the other treatments over the 15 year measurement period. The height of the white oak regeneration established after the treatment was greater for both cut treatments compared to the uncut treatment. The average height of the regeneration is relatively small at this point in time and would not be expected to be competitive if the stands were regenerated with the advanced regeneration in this condition. It is probable that some form of manipulation will be necessary to develop high vigor advanced regeneration prior to a future regeneration harvest. However, the advanced regeneration that developed after treatment indicates that the reserve trees are providing viable propagules which are developing advanced regeneration for future manipulation and stand regeneration.

Densitometer readings were also higher for the cut stands compared to the uncut stands. A positive linear relationship (y = 0.016 + 0.00724(densitometer reading), R^2 = 0.733) was found between densitometer reading and PPFD indicating a relationship between measurable canopy density and light levels at advanced regeneration height (figure 1). A positive relationship was also found between densitometer reading and advanced regeneration height (figure 2) and densitometer reading and advanced regeneration density (figure 3). An exponential relationship was found between densitometer reading and regeneration density (y = 43.615 + 22.373*exp(-densitometer reading/-2.489), R^2 = 0.974) while a linear relationship existed between densitometer reading and regeneration height (y = 0.549+0.0705(densitometer reading), R^2 = 0.743).

The results of this study indicate that small sawtimber sized co-dominant reserve white oak trees are capable of maintaing acorn production and resulting in the production of advanced regeneration that will potentially aid in the long-term maintenance of this species after future regenerative treatments. A positive correlation between canopy density and regeneration height along with the positive correlation between canopy density and light level indicates that light levels developed from the treatments encouraged regeneration development. This data indicates dramatic increases in advanced regeneration density can be obtained when the combined understory, midstory, and overstory exhibit a densitometer reading greater than 6.

REFERENCES

Beck, D.E. 1986. Management options for southern Appalachian hardwoods: the two-aged stand. Phillips, D.R., comp. Proceedings of the Fourth biennial southern silvicultural research conference; 1986 November 4-6, Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 451-454.

David, A.; B. Wender; P. Weis; J. Stringer; D. Wagner. 1998. A new seed trap design. Tree Planters Notes 48(1-2): 35-37.

Miller, G.W.; T.M. Schuler. 1995. Development and quality of reproduction in two-age central Appalachian hardwoods -- 10-year results. In: Proceedings of the 10th Cen. Hardwood For. Conf., K. W. Gottschalk and S. L. C. Fosbroke (eds.). Gen. Tech. Rep. NE-197. U.S. Department of Agriculture, Forest Service. Northeastern Forest Experiment Station: 364-374.

Miller, G. E.; P. B. Wood; J. V. Nichols. 1995. Two-age silviculture -- an innovative tool for enhancing species diversity and vertical structure in Appalachian hardwoods. In: Forest Health through Silviculture -- Proceedings of the 1995 Nat. Silviculture Workshop. L. G. Eskew, comp. Gen. Tech. Rep. RM-GTR-267U.S. Department of Agriculture, Forest Service. Rocky Mountain Forest & Range Experiment Station. Ft. Collins, CO: 175-182.

Nyland, R.D. 1996. Silviculture Concepts and Applications. New York, NY: The McGraw-Hill Companies, Inc. 633 p.

Smith, H.C.; N.I. Lamson; G. W. Miller. 1989. An esthetic alternative to clearcutting? Journal of Forestry. 87: 14-18.

Stringer, J.W. 1998. Two-aged silvicultural systems: diameter distribution and predictive models for determining minimum reserve tree diameters. In: Waldrop, T.A., ed. Proceedings of the Ninth biennial southern silvicultural research conference; 1997 February 25-27, Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 143-147.

Stringer, J.W.; G.W. Miller; R.F. Wittwer. 1988. Costs to Apply Crop-Tree Release in Small Sawtimber White Oak Stands. Res. Pap. NE-620: U.S. Department of Agriculture, Forest Service. 5 p.

OAK REGENERATION: FOUR YEARS AFTER THREE HARVESTING TREATMENTS IN A NORTH ALABAMA UPLAND HARDWOOD STAND

David Shostak, Michael S. Golden, and Mark R. Dubois[1]

Abstract—Fourth year regeneration of upland oaks (*Quercus spp.*) was compared within three harvesting treatments in the mountains of northern Alabama. Six four-acre experimental blocks were established on north facing slopes. Each of the three harvesting treatments (deferment cutting, strip clearcutting, and block clearcutting) was randomly assigned to two treatment blocks. Major oaks present were white oak (*Q. alba*), northern red oak (*Q. rubra*), and chestnut oak (*Q. prinus*). Densities and stocking levels of non-sprout origin non-overtopped oak reproduction were related to treatment, topographic position, and pre-harvest competition cover. The overall contribution of the non-sprout oak regeneration was low. Post harvest germination and advance reproduction contributed equally to the successful fourth year reproduction.

INTRODUCTION

Oak-Hickory forests cover approximately 35 percent (7.7 million acres) of Alabama's timberland with 65 percent of the Oak-Hickory forests found in north Alabama (McWilliams 1992). Upland hardwood stands have been long viewed as valuable. Some of their values can easily be associated with economics, such as the sale of timber or the lease of hunting rights. Unfortunately placing an economic value on aesthetics or wildlife benefits can be difficult. Regardless of the rationale, upland hardwood stands are important and warrant the attention of individuals interested in maintaining and managing these diverse values.

"Oak regeneration is a problem and the problem is widespread. Many of the problems can be solved by utilizing information that is already available, but there is a cost involved, which will have to be addressed by forest managers and forest landowners. Other problems with oak regeneration will require a major research commitment" (Smith 1993a).

In 1996, a permanent study was established in the mountains of northern Alabama to assess the stocking and growth of oak regeneration following three harvesting treatments: block clearcutting, strip clearcutting and deferment cutting. This paper reports on data taken after the fourth full growing season (Fall 2000). This approximates the end of the stand initiation stage, at which point an inference can be made as to the composition of the mature stand.

OBJECTIVES

Two main objectives have been developed for this study: 1) to determine which potential factors had an effect on fourth year post-harvest stand composition; and 2) to investigate which of the studied silvicultural treatments (block clearcutting, strip clearcutting, and deferment cutting) provided for the desired and adequate oak regeneration component. The overall goal of this ongoing study is to identify the influences upon oak regeneration at various times after harvest.

METHODS

Study Site

The site is located in the Sandstone Mountain Forest Habitat Region of northern Alabama on the southern Cumberland Plateau physiographic province (Hodgkins and others 1979). Major ridges typically run east to west. This tract is currently owned and managed by International Paper and is adjacent to the William B. Bankhead National Forest in Lawrence County, AL. Slopes range from five to sixty percent.

The study is located in an upland mixed hardwood forest on north facing slopes and ridge shoulders. Prior to harvest, overstory (trees larger than 5 inches dbh) density was 313 stems per acre with a total basal area of 118.3 square feet per acre (table 1). The stand was composed of a mixture of oak species (*Quercus spp.*), sugar maple (*Acer sacharum*), black tupelo (*Nyssa sylvatica*), American beech (*Fagus grandifola*), and hickories (*Carya spp.*).

Study Design

Six four-acre treatment blocks (400 by 440 feet) were established on north facing slopes. Each of the three harvesting treatments was randomly assigned to two of the experimental blocks. The block clearcutting treatment administered was a silvicultural clearcut; all stems greater than 1.5 inches dbh were cut. The strip clearcutting treatment harvested all stems greater than 1.5 inches dbh in alternating one-acre cut and uncut strips approximately 120

[1]Graduate Research Assistant, Associate Professor, and Associate Professor, School of Forestry and Wildlife Sciences, Auburn University, AL 36849, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Pre-harvest overstory composition, basal area, and advance reproduction and composition of fourth year non-overtopped reproduction, oaks and other species

Fourth year Species	Pre Harvest: Overstory[a]		Advance reproduction[b]	Non-overtopped reproduction[c]
	Ft²/acre	Stems/acre	Stems/acre	Stems/acre
L. tulipifera	9.7	7	2	882
A. saccharum	4.3	8	1229	492
Non-Comm	1.1	4	608	460
Other-Comm	10.7	16	182	404
N. sylvatica	4.4	9	281	363
A. rubrum	2.2	4	408	223
Fraxinus sp.	1.8	4	50	153
Carya sp.	29.0	36	177	131
Quercus sp.	46.6	40	212	112
F. grandifolia	8.5	10	196	52
Total	118.3	138	3345	3272
Q. alba	12.7	13	18	38
Q. rubra	8.5	6	113	32
Q. prinus	22.0	20	57	30
Other oaks[d]	3.4	1	24	12
Total	46.6	40	212	112

[a] Includes canopy trees greater than 5 inches dbh in the harvested areas only.
[b] AR greater than 1 foot tall and less than 1.5 inches dbh.
[c] Represents the 498 plots in the harvested areas.
[d] Mainly black (*Q. velutina*), southern red (*Q. falcata*), and scarlet oaks(*Q. coccinea*).

feet wide and roughly oriented with the contours. The deferment cuts were harvested in a similar fashion, except that a basal area of approximately 25 square feet per acre was left. The reserve trees were selected and marked based upon the criteria that they were evenly spaced, good quality co-dominant oaks (where possible), and more than likely to survive throughout the rotation. Where oaks were not present, other species meeting the criteria were marked and used as reserve trees.

Pre-Harvest Measurements

In 1996, prior to harvest the six treatment blocks were sampled by three 6.6-foot wide permanent belt transects equally spaced and running down slope. Each belt transect includes 67 milacre plots and makes up the center line of a 33-foot wide segment running east to west. This grid system runs the entire length of the block. Each odd numbered plot along the center line was established with metal conduit pipe marking the top corners and the lower boundaries were marked with pin flags. Each milacre plot was divided into quadrants to facilitate the re-measurement and successive counting of reproduction. Oak seedlings were tagged and measured in all quadrants. Counts of all non-oak tree reproduction, by species and size class, were obtained in each measurement plot at each inventory. Size classes were recorded as 1) less than 6 inches, 2) 6-12 inches, 3) 12-36 inches, 4) greater than 36 inches with a diameter less than 1.5 inches, or 5) with a dbh greater than 1.5 inches. Vegetative competition cover and site characteristics were also obtained. Ocular measurements for woody vegetative competition were made to the nearest 5 percent increment and later combined into classes of 0-10, 11-30, 31-70, and 71-100 percent. Overstory data was obtained for the entire one-half chain strip, which provided a 25 percent sample of the treatment blocks. Greater detail on the pre-harvest measurements can be found in Golden and others (1999).

Post-Harvest Measurements

Following the harvest in fall 1996, site and soil impacts were assessed and recorded for each measurement plot. Another detailed survey was conducted using the same procedures as the pre-harvest measurement. Fifteen months (Fall 1997) after harvest the stand was again re-entered and the plots re-located and re-measured, but these are not reported in this paper.

Fourth Year Measurements

In fall 2000, a fourth year re-measurement was conducted. Tagged oak reproduction was re-measured and new reproduction recorded. Non-oak reproduction was inventoried by species and competitive position. Competitive position was recorded as free to grow (FTG), crowded but not overtopped (CR), or overtopped (O). These classes were modified from Smith (1986).

Data Analyses

The data analyses reported in this paper are per acre and stocking comparisons within categories of treatment, topography, and pre-harvest competition cover. The values are derived from the tagged reproduction of non-sprout origin in non-overtopped competitive positions. Sprouts from stems larger than 1.5 inches dbh are not included. Since all oak seedlings were tagged and measured prior to harvest and at each subsequent measurement, a determination of origin could be made. Those seedlings present prior to harvest of any size were classified as advance reproduction (AR) and those seedlings germinating thereafter were classified as post harvest germination (PHG). All plots in the deferment cuts and block clearcuts were used. In the strip clearcuts, only plots in the harvested areas were used. All plots in all the treatments that were used totaled 498. Per acre values for non-oak reproduction were obtained from the non-tagged inventory.

All of the data analyses were accomplished using the Statistical Analysis System (SAS) version 6.12. Simple descriptive statistics were obtained using Proc Means and Proc Freq (SAS Institute Inc 1990).

RESULTS

Pre-Harvest Overstory Composition

The initial stand had 138 stems per acre, 30 percent oak (table 1). The basal area of canopy trees (5 inches and larger dbh) was 118.3 square feet per acre, with oaks the largest component at 39 percent. Of the oaks, chestnut oak (*Q. prinus*) was the most abundant with 50 percent of the total and a basal area of 22 square feet per acre. White oak (*Q. alba*) and northern red oak (*Q. rubra*) also comprised a significant portion of the pre-harvest stand. Remaining oaks were grouped together and classified as other oaks. Most of the oaks were 65-70 years old. From height and age measurements, oak site index was estimated as 70-80 feet (base age 50) on the ridge and upper slopes and 85-100 feet on the middle and lower slopes. Oak numbers were the highest on ridge shoulders and declined down the slope.

The pre-harvest subcanopy density (1.5 - 5 inches dbh) totaled 176 stems per acre. The most abundant species were sugar maple and American beech, which comprised 21 and 18 percent of the stems respectively. Most of the sugar maple and American beech were found on the lower slopes where they dominated the understory. The oaks averaged only 5 stems per acre. These were mainly chestnut oaks located on the ridge shoulders. The most abundant understory species was American hornbeam (*Ostrya virginiana*), at 30 stems per acre (Golden and others 1999).

Advance reproduction

Large advance reproduction (AR), greater than 1 foot tall and less than 1.5 inches dbh, totaled 3,345 stems per acre (table 1). The oak component was low, making up 6 percent (212 stems per acre) of the total large AR. Northern red oak (113 stems per acre) was the most abundant, followed by chestnut oak (57 stems per acre) and white oak (18 stems per acre). Of the non-oak species, sugar maple was the most abundant with 1,229 stems per acre (37 percent), then non-commercial species with 608 stems per acre (18 percent), followed by red maple with 408 stems per acre (12 percent). The least abundant species was yellow poplar (*Liriodendron tulipifera*), with 2 stems per acre.

Fourth Year Non-Overtopped Composition

Overall densities for all species after four years are shown in table 1. Fourth year non-overtopped reproduction totaled 3,272 stems per acre, with the oaks comprising only 3 percent (112 stems per acre). White oak (38 stems per acre)

Table 2—Fourth year composition of non-overtopped oak reproduction in the harvested areas, within treatment, topographic location, and competition class

Factor	Plots	*Q.alba*	*Q.rubra*	*Q.prinus*	Other oaks	All oaks
		.... *Stems per acre*				
Cutting Treatments						
Deferment cut	200	90	60	65	15	230
Strip clearcut	100	0	20	20	10	50
Block clearcut	198	5	10	0	10	25
Topographic Position						
Upper / ridge	121	140	74	74	25	314
Mid	192	5	10	21	5	42
Lower	174	6	29	11	11	57
Pre-Harvest Competition Cover						
0-10 pct	156	109	58	64	19	250
11-30 pct	253	8	16	20	8	51
31-70 pct	85	0	35	0	12	47
71-100 pct	4	0	0	0	0	0

was the most abundant, followed by northern red oak (32 stems per acre) and chestnut oak (30 stems per acre). Of the non-oak species the most abundant was yellow poplar, with 882 stems per acre (27 percent), then sugar maple with 492 stems per acre (15 percent). No other tree species was less abundant than the oak reproduction; American beech had 52 stems per acre, which is higher than any individual oak species count.

Among the harvesting treatments, the deferment cut had the most abundant total oak reproduction, 230 stems per acre (table 2). Of the three major oak species within the deferment cuts, white oak had the highest density (90 stems per acre) with no noticeable difference between northern red oak and chestnut oak. Non-overtopped oaks were scarce in the strip cuts and the block clearcuts (50 and 25 stems per acre respectively), with no obvious differences among major species. Among topographic classes, the upper slope and ridge shoulder positions had the highest non-overtopped oak densities (314 stems per acre). White oak was most abundant (140 stems per acre) on these positions, with no noticeable differences between chestnut and northern red oak. One obvious difference in the lower slope positions was the higher density of northern red oak (29 stems per acre). For the classification by competing vegetative competition cover, fourth year non-overtopped oak reproduction was highest in the 0-10 percent competition class (250 stems per acre) and declined drastically with increased competition cover. White oak had the highest density (109 stems per acre) with no clear distinction between chestnut oak and northern red oak. In the 31-70 percent cover class, northern red oak had 35 stems per acre and white oak and chestnut oak were non-existent. No non-overtopped oak reproduction was established in the 71-100 percent cover class.

Fourth Year Non-Overtopped Stocking of Oaks

Stocking was defined on a plot-by-plot basis. Any plot that contained at least one oak stem in a non-overtopped competitive position was considered stocked. The overall stocking of oak reproduction was very low, only 9 percent (table 3). This extremely low level of stocking is an indication of the challenges faced by foresters and forest managers who want to perpetuate oaks as a major component of future stands.

Oak stocking was highest in the deferment cuts at 18 percent, and was only 5 and 3 percent in the strip and block clearcutting treatments respectively. Oak stocking was very low on all topographic positions, but highest on the ridge shoulders and upper slopes (22 percent). The middle and lower slope locations were stocked at only 4 and 6 percent respectively. There was no noticeable difference among the three major species within treatment and topographic position. Fourth year non-overtopped oak stocking was low at every pre-harvest competition level. The 0-10 percent class had the highest stocking (15 percent) and the 71-100 percent class was un-stocked. The 11-30 and 31-70 percent classes were equally stocked at 6 percent. One noticeable difference among the three major species in the 31 -70 percent class was that chestnut oak was stocked at 5 percent while white oak and northern red oak were unstocked.

Origins of Fourth Year Non-Overtopped Oaks

Successful reproduction for this study is any stem that survived to the fourth year measurements and is in a non-overtopped competitive position. This section focuses on success related to origin. Fourth year non-overtopped reproduction was determined to have originated either from any size advance reproduction (AR) or from post harvest germination (PHG). Numbers of successful oak reproduction were very small. Of these small numbers, more than 50 percent of the non-overtopped overall oak reproduction originated from PHG (58 stems per acre). AR origin repro-

Table 3—Fourth year stocking of non-overtopped oak reproduction in the harvested areas, within treatment, topography, and competition classes

Factor	Plots	*Q.alba*	*Q.rubra*	*Q.prinus*	Other oaks	All oaks
		Percent stocked plots				
Cutting Treatment						
Deferment cut	200	5	6	6	2	18
Strip clearcut	100	0	2	2	1	5
Block clearcut	198	1	0	1	1	3
Topographic Position						
Upper / ridge	121	7	7	7	2	22
Mid	192	1	2	1	1	4
Lower	174	1	1	3	1	6
Pre-Harvest Competition Cover						
0-10 pct	156	5	3	6	2	15
11-30 pct	253	1	2	3	1	6
31-70 pct	85	0	0	5	1	6
71-100 pct	4	0	0	0	0	0
Overall	498	2	3	3	1	9

Table 4—Origins of fourth year non-overtopped oak reproduction in the harvested areas, within treatment, topography, and competition class

Factor	Plots	*Q.alba* AR	*Q.alba* PHG	*Q.rubra* AR	*Q.rubra* PHG	*Q.prinus* AR	*Q.prinus* PHG	Other oaks AR	Other oaks PHG	All oaks AR	All oaks PHG
		Stems per acre									
Cutting Treatment											
Deferment cut	200	35	55	15	45	45	20	10	5	105	125
Strip clearcut	100	0	0	10	10	10	10	10	0	30	20
Block clearcut	198	5	0	5	5	0	0	5	5	15	10
Topographic Position											
Upper / ridge	121	50	91	17	58	41	33	17	8	124	190
Mid	192	5	0	5	0	16	5	0	5	31	10
Lower	174	6	0	6	23	11	0	11	0	34	23
Pre-Harvest Competition Cover											
0-10 pct	156	38	71	13	19	45	19	13	6	109	115
11-30 pct	253	8	0	8	20	12	8	4	4	32	32
31-70 pc	85	0	0	12	35	0	0	12	0	24	35
71-100 pct	4	0	0	0	0	0	0	0	0	0	0
Overall	498	16	22	10	22	20	10	8	4	54	58

duction totaled only 54 stems per acre (table 4). The major oaks, white oak, northern red oak, and chestnut oak, originated at 58, 69, and 67 percent respectively, from PHG. Fourth-year oak stems that originated from stump sprouting are not included here, but will be addresses in another paper.

There was no clear difference in origin among harvesting methods for non-overtopped reproduction of all oaks. However, for the deferment cutting, white oak and northern red oak reproduction originated mainly from PHG (61 and 75 percent respectively). In contrast, 69 percent of the chestnut oak originated as AR. There was no notable difference among species within the strip clearcutting method. One clear difference in the block clearcutting treatments was that white oak originated 100 percent from AR. Among topographic positions, there was a notable difference in the origins of overall successful stems. The majority of all stems in the upper and ridge shoulder positions originated from PHG (61 percent), while mid slope (76 percent) and lower slope (60 percent) locations had most of the successful stems originating from AR. Among species, obvious differences among topographic positions existed. In the upper slope and ridge shoulder positions, white oak (65 percent) and northern red oak (77 percent) mainly originated from PHG, while chestnut oak (55 percent) originated from AR. In the mid slope positions all major oak species mainly originated from AR (white oak 100 percent, northern red oak 100 percent and chestnut oak 76 percent). The lower slope locations had 100 percent of the white oak and chestnut oak originating from AR, while the northern red oak (79 percent) originated mostly from PHG. There was no obvious difference in the origin of fourth year non-overtopped reproduction among pre-harvest competition cover classes for the overall successful stems. However, within competition classes there was a noticeable difference among major oak species. Within the 0-10 percent competition class, the origin of successful white oak and northern red oak reproduction was noticeably higher from PHG (59 and 65 percent respectively). Conversely, the majority of chestnut oak reproduction came from AR (70 percent). Origins for white oak and chestnut oak in the 11-30 percent class are mainly from AR (100 and 60 percent respectively). In contrast, the higher percentage of northern red oak reproduction came from PHG (71 percent). The only species that had obvious differences in the 31-70 percent class was northern red oak, with 74 percent of the successful stems coming from PHG.

DISCUSSION

At only 112 non-overtopped stems per acre and 9 percent plot stocking, the oak component in the fourth year reproduction is severely reduced from that of the pre-harvest stand. It is generally accepted that large advance reproduction is necessary for successful regeneration of oaks (Sander and others 1984, Johnson 1993). It is also well established that obtaining adequate oak reproduction is more difficult on high quality sites, those greater than 70-foot site index (Smith 1993b). Overall this site presented problems in both areas. In the pre-harvest stand oak AR larger than 1 foot tall was quite low, only 212 stems per acre, and was lowest on the middle and lower topographic positions (Golden and others 1999). Site indexes were higher than 70 feet even on the upper slopes and ridge shoulders and exceeded 85 feet on the middle and lower slopes. Fourth year non-overtopped oak stocking and densities were low on all topographic positions, but highest on ridge shoulders and upper slope positions, which were relatively poorer, drier sites.

Fourth year non-overtopped oak densities and stocking declined in the order: deferment cutting, strip clearcutting, and then block clearcutting. A possible reason for this is the increase in logging disturbance in that same order (Dubois and others 1997, Golden and others 1999). Another possible explanation is the amount of canopy left. The impacts posed by the remaining canopy cover might be similar to a nurse tree effect or a shading effect. The leave trees in the deferment cut and edge trees in the uncut strips allowed the oaks to grow in the lightly shaded areas. Other faster growing species would have out competed the oaks if the canopy were completely removed. The origins of the fourth year non-overtopped white oak and northern red oak in the deferment cuts are mainly from PHG. Conversely, the major origin of chestnut oaks in the deferment cut was from AR. Chestnut oak can persist for many years in the understory on poorer quality sites and can react quickly to release (Burns and Honkala 1990). The higher percent of successful oak reproduction that came from PHG was surprising. However, it is possibly a reflection of the overall small AR numbers. Where the higher numbers of PHG were observed, the deferment trees remained and provided seed. In addition, white oak seed germinates in the fall and its acorns have a 50-90 percent germination capacity (Burns and Honkala 1990).

By the fourth year, a large amount of oak reproduction was overtopped by competing vegetation therefore not considered "successful". Sixty seven percent of the plots had pre-harvest competition cover exceeding 10 percent. Under this severe competition the slower growing oaks tend to fall behind. Once the canopy was fully removed, the faster growing species were able to out compete the majority of oak reproduction, overtopping it by age four.

CONCLUSIONS

Oak densities (112 stems per acre) and stocking levels (9 percent) were very low for all factors affecting fourth year non-overtopped reproduction from non-sprout origins. Oak densities and stocking percentages were highest in the deferment cutting treatments as compared to the strip and block clearcutting treatments. Higher numbers and stocking levels were also found at the upper slope and ridge shoulder positions and declined substantially on the middle and lower slope locations. As pre-harvest competition levels increased oak stocking and densities decreased. For all oaks approximately 50 percent of the fourth year non-overtopped reproduction originated from post harvest germination. The majority of white oak and northern red oak originated as post harvest germination. However, the majority of chestnut oak stems originated from advance reproduction. The contribution of the non-sprout oak regeneration to the future stand will be low. Reproduction from sprout origin will be assessed in a subsequent paper.

ACKNOWLEDGMENTS

This research is part of an ongoing study and is partially supported with grants from the USDA Andrews Forest Service Lab in Auburn, Alabama and by grants from International Paper Corp. (formerly Champion International Corp.).

REFERENCES

Burns, R.M.; Honkala, B.H.; Technical Coordinators. 1990. Silvics of North America: Volume 2. Hardwoods. Agricultural Handbook 654. Washington, DC. U.S. Department of Agriculture, Forest Service. 877 p.

Dubois, Mark R.; Stockman, Jeffery L.; Golden, Michael S. 1997. Silvicultural assessment of alternative harvesting treatments in north Alabama upland hardwood forests. In: Proceedings, Annual Hardwood Symposium of the Hardwood Research Council: 113-122.

Golden, Michael S.; Dubois, Mark R.; Stockman, Jeffery L. 1999. Oak regeneration following three cutting treatments on mountain slopes in north Alabama. In: James D. Haywood, ed. Proceedings of the tenth Biennial Southern Silvicultural Research Conference; 1999 February 16-18; Shreveport, Louisiana. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service Southern Research Station: 8-14.

Hodgkins, E.J.; Golden, M.S.; Miller, W.F. 1979. Forest habitat regions and types on a photomorphic-physiographic basis: a guide to forest site classification in Alabama-Mississippi. Southern Cooperative Ser. Bull. 210. Auburn, AL: Auburn University, Alabama Agricultural Experiment Station. 64 p.

Johnson, Paul S., 1993. Sources of oak reproduction. In: Loftis, David L.; McGee, Charles, E., eds. Oak regeneration: serious problems, practical recommendations: Symposium proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Ashville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 112-131.

McWilliams, W.H. 1992. Forest resources of Alabama. Resource Bulletin SO-170. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 71 p.

Sander, Ivan L.; Johnson, Paul S.; Rogers, Robert. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. Research Paper NC-251. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 16 p.

SAS Institute Inc. 1990. SAS procedures guide, version 6. 3rd ed. Cary, NC: SAS Institute Inc. 705 p.

Smith, David M. 1986. The practice of silviculture. 8th ed. New York: John Wiley & Sons. 527 p.

Smith, David Wm., 1993a. Oak regeneration: the scope of the problem. In: Loftis, David L.; McGee, Charles, E., eds. Oak regeneration: serious problems, practical recommendations: Symposium proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Ashville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 40-51.

Smith, H. Clay, 1993b. Regenerating oaks in the central Appalachians. In: Loftis, David L.; McGee, Charles, E., eds. Oak regeneration: serious problems, practical recommendations: Symposium proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Ashville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 211-221.

STUMP SPROUTING 2 YEARS AFTER THINNING IN A CHERRYBARK OAK PLANTATION

Brian Roy Lockhart, Jim L. Chambers, and Kristi L. Wharton[1]

Abstract–Stump sprouts are considered an important regeneration source in hardwood management, especially in upland oak-dominated forests. Less is known about stump sprouting in bottomland oak forests. Therefore, the objective of this study was to determine the success and growth of stump sprouts following 2 thinning levels, 70-75 percent of initial stocking (light thinning) and 45-50 percent of initial stocking (heavy thinning) in a 35-year-old cherrybark oak (*Quercus pagoda* Raf.) plantation in Concordia Parish, LA. Two growing seasons after thinning, cherrybark oak sprout success was 37 percent across the study site, a 200 percent decrease from the previous year. A severe drought occurred during this time and may have contributed to the low sprouting success. Stumps averaged 8.5 sprouts over the 2-year study period, and dominant sprouts were 82 inches tall. Results from this study indicate that greater weights should be placed on stump sprout potential in bottomland hardwood regeneration evaluation models.

INTRODUCTION

Sprouts are generally defined as shoots arising from the base of woody plants or as suckers from roots (Helms 1998). Though called various names, tree sprouts can usually be divided into 3 types for management purposes: seedling sprouts, root sprouts, and stump sprouts. Seedling sprouts are stems that arise from existing or severed seedlings or saplings (≤3 inches dbh) where the root system may be several to many years older than the stem (McQuilkin 1975). Root sprouts, or suckers, arise from adventitious suppressed buds on root systems of existing or severed trees (Kormanik and Brown 1967). Stump sprouts arise from the base of severed stems and can appear anywhere from the top to the base of the stump.

Stump and root sprouts are considered one of three broad classes of oak reproduction (Aust and others 1985), the others being new seedlings that develop from acorns which germinated just before or soon after harvest and advance regeneration – older regeneration living underneath a forest canopy (Smith and others 1997). Advance regeneration and sprouts have long been considered the most important source of hardwood regeneration, especially for the various oak species (Hodges 1987, Johnson 1994). Sprout survival and development have been well-studied for a variety of upland oak species including northern red oak (*Quercus rubra* L.) (Johnson 1975, Johnson and Rogers 1980), black oak (*Q. velutina* Lam.) (Johnson and Sander 1988), white oak (*Q. alba* L.) (McQuilkin 1975, Lynch and Bassett 1987), and others (Cobb and others 1985, Lowell and others 1987). This information has been incorporated into several hardwood regeneration evaluation models designed to determine if sufficient density and stocking of oak regeneration exists prior to a harvest for regeneration success (Sander and others 1976, Johnson 1977, Sander and others 1984, Dey 1993, Dey and others 1996).

Less is known about the role of sprouting in the regeneration of bottomland oak species (Gardiner and Helmig 1997, Golden 1999). The stump sprouting component of bottomland hardwood regeneration evaluation models rely on the best information currently available, i.e., personal observations, results from upland oak sprouting research, and limited bottomland oak sprouting research (Johnson 1980, Johnson and Deen 1993, Hart and others 1995, Belli and others 1999). Therefore, the objective of this study was to add to the sprouting knowledge of bottomland oak species. Specifically, we examined success and growth of cherrybark oak (*Q. pagoda* Raf.) stump sprouts following two intensities of thinning in a 35-year-old plantation. Two-year results are reported.

MATERIALS AND METHODS

Study Site Description

The study site is located on the Red River Wildlife Management Area in Concordia Parish, east-central LA. Physiographically, the site is located in the Natural Levee Subregion, Mississippi River Floodplain Region of the Alluvial Floodplain Province (Evans and others 1983) and is protected from flooding by the mainline levee system. Soils are composed of Commerce silt loam (Aeric Fluvaquents) and Bruin silt loam (Fluvaquentic Eutrudepts). The former soil is deep and somewhat poorly drained while the latter soil is deep and moderately well drained. Rainfall averages 59 inches per year and is generally evenly distributed throughout the year although periodic summer droughts occur (Evans and others 1983). Average temperature is 67 degrees Fahrenheit with a high of 81 degrees Fahrenheit in July and August (Evans and others 1983). Cherrybark oak site index, base age 50 years, was estimated at 110 feet (Baker and Broadfoot 1979).

[1]Associate Professor, Professor, and Graduate Research Assistant, School of Forestry, Wildlife, and Fisheries, Louisiana Agricultural Center, Louisiana State University, Baton Rouge, LA 70803, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

The plantation was established on a 350-acre agriculture field during 1969-1972. Planting density was variable but averaged 411 seedlings per acre. Cherrybark oak planting accounted for 43 percent of the total area and was primarily located in one portion of the field.

Treatments

Fifteen, 1.8-acre rectangular plots (396 by 198 feet) were established in the cherrybark oak portion of the plantation. Each plot consisted of a 0.4-acre interior measurement plot (264 by 66 feet) with the remaining area as buffer. Diameter of all trees ≥ 5 inches dbh was measured in each interior plot and a hand-drawn map was made for the location of each tree for future reference. These data were used to determine initial stocking using Goelz's (1995) stocking guide for southern bottomland hardwoods. Plots were then blocked, 3 plots per block, by initial stocking to reduce pre-harvest variation among treatments. Overall stocking among the plots was 89 percent, with average stocking among the plots in each block ranging from 76 percent in the lightest stocked block to 104 percent in the heaviest stocked block.

Three thinning treatments were randomly assigned to the plots in each block. These treatments included a light thinning in which stocking was reduced 70-75 percent, a heavy thinning which reduced stocking to 45-50 percent, and an unthinned control. Tree marking guidelines were developed using the stocking information along with a tree class system (species, crown class, and butt-log grade) to determine those trees that would serve as future crop trees (preferred stock), those trees which could remain until the next thinning or could be marked for the present thinning (reserve stock), and those trees that should be removed in the present thinning operation (cutting stock) (Putnam and others 1960, Meadows 1996). All cutting stock trees were marked then reserve stock trees were marked as needed until the desired residual stocking was attained. Thinning operations were conducted from 30 September 1998 through 3 February 1999 across the plantation. A total of 141 cherrybark oak trees were harvested in the treatment plots.

Measurements

Assessments were made of each cherrybark oak stump during the 1999/2000 and 2000/2001 dormant seasons, representing the 1999 and 2000 growing seasons, respectively. Observations were noted as to whether the stump sprouted, how many sprouts were present, and the height of the tallest sprout (in centimeters) for each stump when 2 or more sprouts were present. Due to the prolifera-tion of sprouts in a small location on many stumps, only those sprouts that were ≥ 1 foot tall and located within 3 inches of the stump were counted. These criteria allowed us to distinguish sprouts from branches within a sprout and to avoid counting stems that paralleled the surface of the ground despite being as long as 3 feet. On dead sprouts, we noted if they had initiated growth prior to their death.

Analyses

Sprout success, calculated as the number of stumps with at least one living sprout divided by the total number of

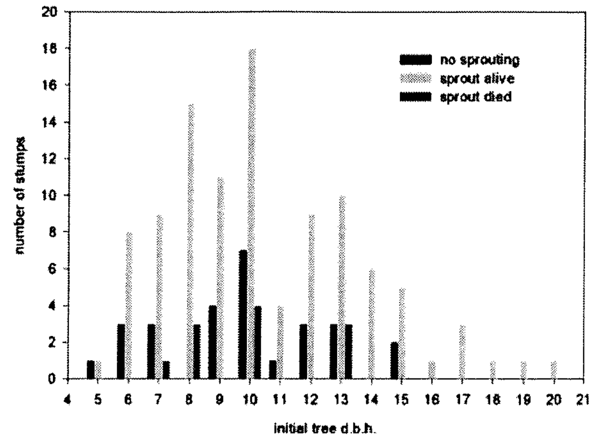


Figure 1—1999 diameter distribution of cherrybark oak sprouting success for light and heavy thinning treatments on the Red River Wildlife Management Area, Concordia Parish, LA.

stumps, sprout numbers per stump, and height of the tallest sprout on each stump were analyzed using analysis-of-variance in a randomized complete block design. Initial stocking density represented the blocking factor. Since controls contained no stumps, only two treatments, light thinning and heavy thinning, were included in the analyses. Regression techniques were also used to determine if relationships existed between the variables and pre-harvest tree diameter. All analyses were done using PC-SAS (SAS 1985). An alpha level of 0.05 was used to determine significant differences. Height values were converted to English units for reporting purposes.

RESULTS AND DISCUSSION

Sprout Success

One growing season after thinning 81 percent of the cherrybark oak stumps had sprouted. Sprouting occurred for all diameter classes with nearly 100 percent sprouting for trees ≥ 14 inches (n = 20) (figure 1). Eleven of these sprouts died during the year for a sprouting success of 73 percent (table 1). Sprout success in the light thinning treatment was greater than in the heavy thinning treatment,

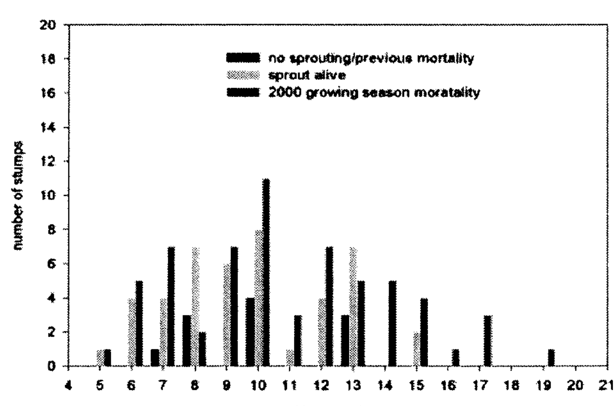


Figure 2—2000 diameter distribution of cherrybark oak sprouting success for light and heavy thinning treatments on the Red River Wildlife Management Area, Concordia Parish, LA.

Table 1–Stump sprout characteristics two years after light and heavy thinning in a cherrybark oak plantation on the Red River Wildlife Management Area

	Sprout Success (percent)				No. Sprouts per Stump				Height (cm)				Ht. Growth (cm)	
Treat-ment	1999		2000		1999		2000		1999		2000		2000	
Light	79a[1]	1.1[2]	33a	4	8	1.1	10	1.7	60	4	79	13	12	9
Heavy	66b	3.4	44b	5	9	0.8	7	0.9	60	2	86	3	28	3
p-value	.0010		.0066		.9444		.3181		.9242		.6479		.2392	

[1] Numbers followed by different letters within a column are significantly different at p 0.05.
[2] The second column within each growing season represents ±1 standard error.

79 percent to 66 percent, respectively (table 1). Greater success in the light thinning may be attributed to a greater number of trees harvested in the smaller dbh size classes, especially the 6- and 8-inch dbh classes, with subsequent greater sprouting potential (figure 1). Greater sprouting for smaller-sized trees has been reported for other oak species (Johnson 1975, Golden 1999). Sprouting success differences also existed between blocks (initial tree stocking) although no discernable patterns existed.

Sprout success dropped considerably the second year after thinning (2000 growing season). Success was only 37 percent across the study site, a 200 percent decrease from the previous growing season (figure 2). Mortality was distributed across the range of dbh but was most pronounced in the 8- and 10-inch dbh classes (figure 2). The likely cause for this increased sprout mortality was the severe drought that occurred during the two-year study period. Rainfall totals at the Marksville, LA station (about 15 miles southwest of the Red River WMA) were 75 percent and 72 percent of normal for 1999 and 2000, respectively. Twenty-four sprouts (17 percent of the total number of stumps) perished during the second growing season. Many of these sprouts grew well during the early growing season with multiple flushes, flush lengths $\geq$ 1 foot, and leaves distributed along the stem of each flush—all signs of good sprout vigor. Unlike the previous growing season, success was greater in the heavy thinned plots compared to the light thinned plots, 42 percent to 32 percent, respectively (table 1). With a greater number of trees thinned, the heavy thinned plots may have had less below-ground competition with a subsequent greater amount of soil moisture available for the stump sprouts. Differences continued to exist in sprout success between blocks but, as with the 1999 growing season, no discernable patterns existed.

Gardiner and Helmig (1997) reported 100 percent survival of stump sprouts 1 year following light and heavy thinning in a 28-year-old water oak (*Q. nigra* L.) plantation. Survival decreased considerable by year 2 and followed a gradual decline through year 7. No differences in survival occurred between the thinning treatments until year 7 when survival in the heavy thinning was 23 percent greater than in the light thinning. Gardiner and Helmig (1997) attributed this difference to early crown closure and subsequent decreased light levels in the lightly thinned plots. Similar results, despite the heavy influence of the recent drought, are expected with cherrybark oak in the present study as the overstory canopy should close earlier in the light thinned plots. Golden (1999) reported only 13 percent of cherrybark oak trees had sprouts 3 years following clear felling in 0.8-acre openings. He attributed this low sprouting success primarily to the initial large tree sizes and subsequent large stump sizes. Sprouting success has been shown to decrease with increasing parent tree diameter (Johnson 1975), possibly due to the inability of suppressed buds to break through the thicker bark associated with larger trees or the inability of sprouts to produce enough food to keep the large root system alive.

Sprout Number

Sprout numbers per stump varied little between treatments and growing seasons (table 1). Sprout numbers averaged 8.5 across both years. Self-thinning within sprout clumps has yet to occur. Apparently, the aforementioned drought has had little effect on survival within sprout clumps compared to sprouting success.

Gardiner and Helmig (1997) noted that 1-year-old water oak sprout clumps averaged 15 stems per stump. They also noted that thinning level did not affect the initial stem number per sprout clump. Their results showed considerable within-stump sprout mortality through the first 4 years before stabilizing at about 4 stems per sprout clump by age 7. A decrease in the stem number per sprout clump was not found with cherrybark oak during the 2 growing seasons. Longer term results are needed from the present study with cherrybark oak before more direct comparisons can be made with the sprout number per stump with water oak.

Height

Height of the tallest sprout within each sprout clump averaged 60 inches one year after thinning. Heights generally increased with increasing tree dbh ($r^2 = 0.68$ for simple linear regression), ranging from 48 inches for the 6-inch dbh class to 107 inches for the 20-inch dbh class (figure 3). Mean height increased to 82 inches following the 2000 growing season, although this represented a 27 percent decrease in height growth from the previous year. The trend of increasing heights with increasing dbh class

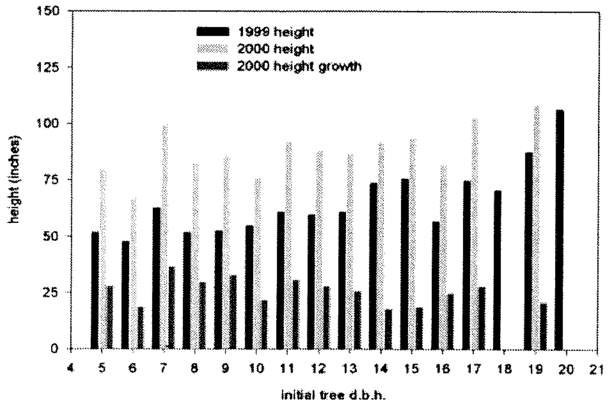


Figure 3—Distribution of 1999 and 2000 cherrybark oak sprout heights and 2000 cherrybark oak sprout height growth by dbh class on the Red River Wildlife Management Area, Concordia Parish, LA.

remained evident, though not as strong, in the second growing season (r^2 = 0.42, figure 3). Thinning regime did not influence sprout height during either growing season (table 1).

A pattern of decreasing height growth with increasing sprout age has been noted by others (Cobb and others 1985, Gardiner and Helmig 1997). Cobb and others (1985) found annual reductions in height growth of scarlet oak (*Q. coccinea* Muenchh.) sprouts ranged from 7-33 percent during the first 5 years of development following clearcutting in the upper Piedmont of South Carolina. Gardiner and Helmig (1997) also found sprout height growth decreased following thinning in a water oak plantation, from 20 inches annual growth for the first 5 years to 11 inches annual growth the next 2 years. Apparently, the rapid early height growth experience by sprouts decreases over time as the above-ground and below-ground portions of each sprout comes into balance.

CONCLUSIONS

Information on oak sprout development following partial cutting in southern bottomland forests is limited. Findings from this study with cherrybark oak in a thinned plantation are generally in agreement with Gardiner and Helmig's (1997) study of water oak sprout development in a thinned water oak plantation. Stump sprout success and growth are dependent on available resources. As these resources, especially light, diminish, slower growth and increased mortality should be expected. Therefore, future thinnings will be necessary to prolong the success and growth of these sprouts. Gardiner and Helmig (1997) mentioned thinning within sprout clumps could possibly extend sprout survival and growth, based on work conducted with upland oak species (Johnson and Rogers 1984, Lowell and others 1987). Such treatments require additional research with bottomland hardwood species.

Hart and others (1995) recent modification of Johnson's (1980) bottomland hardwood regeneration evaluation model gives 3 points for trees 2-5 inches dbh, 2 points for trees 6-10 inches dbh, 1 point for trees 11-15 inches dbh, and no points to trees ≥ 16 inches dbh. A minimum of 12 points is needed for a 0.01-acre regeneration plot to be considered adequately stocked with regeneration or regeneration potential from stump sprouts. It would take 4 trees in the smallest dbh class or 12 trees in the 11-15 inch dbh class for a plot to be considered stocked, assuming no other trees were present in the plot. Data used in the modification of Johnson's (1980) model involved primarily seedlings and saplings; limited data existed for trees ≥ 4 inches dbh to adequately evaluate the role of stump sprouts in regenerating bottomland hardwood stands (Hart and others 1995, Belli and others 1999). Results from this study indicate that more weight should be given to trees in larger size classes, especially if drought induced mortality is removed. However, the present study was limited to only 141 harvested cherrybark oak trees growing on an excellent site which was subjected to unusual weather conditions over the past 2 years. Furthermore, the current bottomland hardwood regeneration model was developed for use in stands that will receive a regeneration harvest; the subsequent regeneration will respond to open conditions. The present study involved trees that were harvested as part of a thinning operation in which an overstory canopy still exists. Shading from this overstory will influence future development of oak sprouts. Also, sprouts in the present study arose from trees that were judged to be inferior to the residual trees; therefore, sprout development from these trees may differ from sprouts which develop from the residual crop trees. Much work remains on the role of stump sprouts in regenerating bottomland hardwood stands; this includes both oak and non-oak species.

ACKNOWLEDGMENTS

The authors thank the Louisiana Department of Wildlife and Fisheries for their support with installing the cherrybark oak thinning study. Emile Gardiner provided constructive comments on an earlier draft of this manuscript.

REFERENCES

Aust, W.M.; Hodges, J.D.; Johnson, R.L. 1985. The origin, growth and development of natural, pure, even-aged stands of bottomland oak. In:Shoulders, Eugene, comp. Proceedings of the third biennial southern silvicultural research conference; 1984 November 7-9; Atlanta, GA. Gen. Tech. Rpt. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 163-170.

Baker, J.B.; Broadfoot, W.M. 1979. A practical field method of site evaluation for commercially important southern hardwoods. Gen. Tech. Rpt. SO-26. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 51 p.

Belli, K.L.; Hart, C.P.; Hodges,J.D.; Stanturf,J.A. 1999. Assessment of the regeneration potential of red oaks and ash on minor bottoms of Mississippi. Southern Journal of Applied Forestry. 23: 133-138.

Cobb, S.W.; Miller, A.E.; Zahner, R. 1985. Recurrent shoot flushes in scarlet oak stump sprouts. Forest Science. 31: 725-730.

Dey, D.C. 1993. Predicting quantity and quality of reproduction in the uplands. In: Loftis,David L.; McGee,Charles E., eds. Oak regeneration: serious problems, practical recommendations: Symposium proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 138-145.

Dey, D.C.;Ter-Mikaelian, M.; Johnson, P.S.; Shifley, S.R. 1996. Users guide to ACORn: a comprehensive Ozark regeneration simulator. Gen. Tech. Rpt. NC-180. St. Paul: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 35 p.

Evans, D.L.; Burns, P.Y.; Linnartz, N.E.; Robinson, C.J. 1983. Forest habitat regions of Louisiana. Res. Rpt. No. 1. Baton Rouge, LA: Louisiana State University Agricultural Center, School of Forestry and Wildlife Management. 23 p.

Gardiner, E.S.; Helmig, L.M. 1997. Development of water oak stump sprouts under a partial overstory. New Forests. 14: 55-62.

Goelz, J.C.G. 1995. A stocking guide for southern bottomland hardwoods. Southern Journal of Applied Forestry. 19: 103-104.

Golden, M.S. 1999. Factors affecting sprouting success in a bottomland mixed hardwood forest. In: Haywood, James D., comp. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16-18; Shreveport, LA. Gen. Tech. Rpt. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 157-163.

Hart, C.P.; Hodges, J.D.; Belli, K.L.; Stanturf, J.A. 1995. Evaluating potential oak and ash regeneration on minor bottoms in the Southeast. In: Edwards, M. Boyd, comp. Proceedings of the eighth biennial southern silvicultural research conference; 1994 November 1-3; Auburn, AL. Gen. Tech. Rpt. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 434-442.

Helms, J.A. (ed.). 1998. The dictionary of forestry. The Society of American Forestry, Bethesda, MD. 210 p.

Hodges, J.D. 1987. Cutting mixed bottomland hardwoods for good growth and regeneration. In: Proceedings of the fifteenth annual hardwood symposium of the hardwood research council; 1987 May 10-12. Memphis, TN: National Hardwood Lumber Association: 53-60.

Johnson, P.S. 1975. Growth and structural development of red oak sprout clumps. Forest Science. 21: 413-418.

Johnson, P.S. 1977. Predicting oak stump sprouting and sprout development in the Missouri Ozarks. Res. Pap. NC-149. St. Paul: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 11 p.

Johnson, P.S. 1994. The silviculture of northern red oak. Gen. Tech. Rpt NC-173. St. Paul: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 22-68.

Johnson, P.S.; Rogers,R. 1980. Predicting growth of individual stems within northern red oak sprout clumps. In: Garrett, Harold E; Cox, Gene S., eds. Proceedings of the third central hardwood forest conference; 1980 September 16-17; Columbia, MO: University of Missouri-Columbia: 420-439.

Johnson, P.S.; Rogers,R. 1984. Predicting 25th-year diameters of thinned stump sprouts of northern red oak. Journal of Forestry. 82: 616-619.

Johnson, P.S.; Sander, I.L. 1988. Quantifying regeneration potential of *Quercus* forests in the Missouri Ozarks. In: Ek, Alan R.; Shifley, Stephen R.; Burk, Thomas E., eds. In: Proceedings, IURFRO conference on forest growth modeling and prediction. Volume 1; 1987 August 23-27; Minneapolis, MN. Gen. Tech. Rpt. NC-120. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northcentral Forest Experiment Station: 377-385.

Johnson, R.L. 1980. New ideas about regeneration of hardwoods. In: Proceedings, Hardwoods regeneration symposium;1980 January 29;Atlanta.Forest Park, GA: Southeastern Lumber Manufacturing Association: 17-19.

Johnson, R.L.; Deen, R.T. 1993. Prediction of oak regeneration in bottomland forests. In: Loftis,David L.; McGee,Charles E., eds. Oak regeneration: serious problems, practical recommendations: Symposium proceedings; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 146-155.

Kormanik, P.P.; Brown, C.L. 1967. Root buds and the development of root suckers in sweetgum. Forest Science. 13: 338-345.

Lowell, K.E.; Mitchell, R.J.; Johnson, P.S.; Garrett, H.E.; Cox, G.S. 1987. Predicting growth and success of coppice-regenerated oak stems. Forest Science. 33: 740-749.

Lynch, A.M.; Bassett, J.R. 1987. Oak stump sprouting on dry sites in northern lower Michigan. Northern Journal of Applied Forestry. 4: 142-145.

McQuilkin, R.A. 1975. Growth of four types of white oak reproduction after clearcutting in the Missouri Ozarks. Res. Pap. NC-116. St. Paul: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 5 p.

Meadows, J.S. 1996. Thinning guidelines for southern bottomland hardwood forests. In: Flynn, Kathryn M., ed. Proceedings of the southern forested wetlands ecology and management conference; 1996 March 25-27; Clemson, SC. Consortium for Research on Southern Forested Wetlands: 98-101.

Putnam, J.A.; Furnival, G.M.; McKnight, J.S. 1960. Management and inventory of southern hardwoods. Agric. Handb. 181. Washington, DC: U.S. Department of Agriculture. 102 p.

Sander, I.L.; Johnson,P.S.; Rogers,R. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. Res. Pap. NC-251. St. Paul: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 16 p.

Sander, I.L.; Johnson, P.S.; Watt, R.F. 1976. A guide for evaluating the adequacy of oak advance reproduction. Gen. Tech. Rpt. NC-23. St. Paul: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 7 p.

SAS. 1985. SAS/STAT guide for personal computers, version 6. SAS Institute, Inc. Cary, NC: 378p.

Smith, D.M.; Larson, B.C.; Kelty, M.J.; Ashton, P.M.S. 1997. The practice of silviculture: applied forest ecology. 9th ed. John Wiley. 537 p.

REPRODUCTION IN GROUP SELECTION OPENINGS 8 YEARS AFTER HARVEST IN A BOTTOMLAND MIXED HARDWOOD FOREST

Michael S. Golden[1]

Abstract—Eight-year reproduction was inventoried in permanent plots in 10 small patch cuts in a mixed bottomland forest by the Tombigbee River in western Alabama. Overall, there was adequate reproduction of commercial tree species (1174 stems per acre), but there were some scattered unstocked areas. The overall reproduction of oaks was relatively poor (an average of 340 per acre and less than 20 percent milacre plot stocking) and cherrybark, Shumard, and swamp chestnut oak reproduction was probably not sufficient to recover their proportions that existed in the preharvest overstory. Water/willow oaks were more successful than the other oaks and may attain equal or higher levels in the future stand compared to the preharvest overstory. Understocked areas in the patches resulted primarily from development of heavy woody vine and shrub cover, with grapevine the most important problem. The eight-year stocking of oaks originated primarily from advance reproduction less than one foot tall and from post harvest germination of acorns. The contribution of large advance oak reproduction was very small, due to the very low numbers present before harvest.

INTRODUCTION

The objectives of this paper are (1) to assess natural reproduction success for oaks and other major tree species eight years after harvesting small patches in a river bottomland mixed hardwoods forest; and (2) to examine the relative role of advance reproduction and post-harvest germination in establishing reproduction on this site.

STUDY SITE

The study was established in 1992 in a 75 acre stand of oak-dominated mixed bottomland hardwoods in the floodplain of the Tombigbee River, in Choctaw County, Alabama. The property is owned and managed by Ft. James Corporation. Physiographically, the site is in the Hilly Coastal Plain Province (Hodgkins and others 1979) and is just south of and downstream from the Black Belt.

At the time of cutting, the stand was predominately bottomland mixed oak forest, with the dominant canopy mostly 65-75 years old and 110-135 ft tall. The area of the study is a mixture of low, well-drained ridges and moderately to somewhat poorly-drained flats. The dominant soils are of the Mooreville, Urbo, and Una series. Surface horizons are mostly loam to silt loam. Typically, most of the sites are covered by river floodwater for brief periods once or twice during the winter and spring. The flats can also fill with water from rainfall, resulting in their having surface water 1-3 inches deep even in late spring.

STUDY DESIGN

Rectangular clearcut patches of 0.8 acre, 132 by 264 ft, were the basic units of the study. These were small clearcuts, but this size falls within acceptable size limits for a group selection regeneration method (Smith and others 1996), since they approximate one tree height wide by two tree heights long. Ten patches, centered among clusters of larger dominants and oriented generally east-west, were delineated.

Five patches were randomly selected and harvested in early June, 1992 and the remaining five were harvested in early October, 1992. These were operational commercial harvests conducted by loggers contracted by Linden Lumber Company of Linden, Alabama. Trees were felled by chainsaws, delimbed and topped where they fell, and pulled by grapple skidders to one of two centrally-located loading decks. Following the commercial harvests, all remaining trees in the openings that were larger than 2 inches dbh were felled. When measured by remaining perimeter trees, all of the cut openings were slightly more than 0.9 acre in size. In aggregate, the ten cut patches totaled approximately 9.1 acres.

DATA COLLECTION AND ANALYSIS

Prior to harvest, all trees in each patch greater than 10 ft tall were inventoried and their locations mapped. Species and dbh were recorded for each tree.

[1]Associate Professor, School of Forestry and Wildlife Sciences, Auburn University, Al 36849.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Preharvest stems per acre, basal area, and dbh's for trees larger than 5 inches dbh, all ten patches combined

Species	Stems/ac	Ft^2/ac	DBH (in.) Mean	DBH (in.) Maximum
Quercus pagoda	14	46.7	23.6	44.5
Quercus phellos	6	20.6	23.3	38.7
Liquidambar styraciflua	28	20.2	10.6	29.3
Quercus nigra	6	17.6	21.2	40.4
Quercus michauxii	5	8.8	15.1	40.4
Quercus shumardii	1	4.3	22.5	31.1
Fraxinus pensylvanica	5	4.1	11.0	27.6
Celtis laevigata	5	3.3	10.3	20.5
Carpinis caroliniana	12	2.6	6.3	11.9
Quercus lyrata	1	2.1	16.0	32.8
Carya spp.	2	1.9	11.0	21.0
Carya ovalis	1	1.5	4.1	16.6
Carya cordiformis	2	1.1	5.1	21.8
Carya ovata	2	0.9	8.2	18.1
Quercus laurifolia	<1	0.8	21.2	25.2
Nyssa sylvatica	2	0.6	7.7	12.1
Morus rubra	1	0.4	7.0	9.9
Ulmus Americana	1	0.3	6.8	10.0
Carya tomentosa	1	0.2	7.7	10.8
Ilex opaca	<1	0.2	8.9	12.6
Ulmus spp.	<1	0.1	6.1	6.7
Halesia diptera	<1	0.1	5.9	7.2
Ulmus alata	<1	0.1	6.3	7.4
Ilex decidua	<1	<0.1	6.3	7.2
Crataegus spp.	<1	<0.1	6.0	6.0
Totals	96	134.0		

For inventory and long-term monitoring of reproduction, seven systematically-placed belt transects, each 6.6 ft wide and extending from side to side perpendicular to the long axis, were established in each patch. These were segmented into 1 milacre (6.6 by 6.6 ft) subplots, with 20 subplots in each transect within the patch boundaries, for a total of 140 milacre subplots within each patch. The subplot corners were marked with wire pin flags, which were replaced by plastic pipe stakes after the harvests.

All non-vine woody species were tallied by species and size class within each subplot before harvesting and several times since. The forest surrounding the developing patches was commercially clearcut in late summer, 1999. The last reproduction plot inventory was conducted in early June, 2000, eight years after the first harvests. Tree reproduction in the milacre plots were re-inventoried by species and competitive position class. To characterize and discuss the eight-year reproduction, only those trees considered "non-overtopped" (NOT) were included. This category is composed of trees with no competing trees having live foliage directly overtopping the tip. This includes those judged "free-to-grow", with no taller trees intersecting a 90 degree exclusion angle with the apex at the growing tip (Smith and others 1996) and those with slightly taller, crowding trees nearby, but with no foliage directly overtopping them ("free tip"). It was felt that all of these had at least some chance of ultimately being in the canopy. In the third decade after harvest, cherrybark oak has been found to be able to gain dominance over sweetgums that had earlier crowded them and been taller (Clatterbuck and Hodges 1988). Those trees completely overtopped were excluded from the analyses, regardless of height, and considered to have lost the battle for space in the developing canopy.
At the eight-year inventory, several hundred of the original reproduction plots were judged too heavily damaged by the 1999 timber harvest and were omitted from further analyses. Data from the remaining 954 plots were summarized by species and competition class and compared to preharvest data from the same 954 plots and to the total preharvest overstory inventory.

RESULTS AND DISCUSSION

Preharvest Trees

Before harvest, the overstories of all of the patches were dominated in basal area by oaks. Taken together, the oaks averaged 100.9 ft^2 per acre. Cherrybark oak (*Quercus* *pagoda* Raf.) averaged the highest basal area (table 1). It was present in the overstory of all ten of the patches, with a minimum basal area of 17.7 ft^2 per acre and a maximum of 95.1 ft^2 per acre. However, most of the trees were large and its canopy numbers were relatively small, averaging only 14 stems per acre. Willow oak (*Q. phellos* L.) was second in overall dominance (20.6 ft^2 per acre), but it averaged only 6 stems per acre. Water oak (*Q. nigra* L.) was present in the overstories of all ten patches, but was fourth overall in basal area and averaged only 6 stems per acre. Swamp chestnut oak (*Q. michauxii* Nutt.) was present in nine of the ten patches, but was never a leading dominant. Shumard oak (*Q. shumardii* Buckl.) was a leading species in one patch and present in another, but was absent from the other eight patches. Two other oaks, overcup (*Q. lyrata* Walt.) and swamp laurel oak (*Q. laurifolia* Michx.) were present but were scattered and in very low numbers within the patches. Sweetgum (*Liquidambar styraciflua* L.) was third in species average basal area (20.2 ft^2 per acre) and first in average stem density with 28 per acre (table 1). It was present in all patches. Green ash (*Fraxinus pennsylvanica* Marsh.) and sugarberry (*Celtis laevigata* Willd.) were present in most of the patches, but were never among the dominant species.

Advance Reproduction

For the analyses and the discussion here, a broad interpretation of "advance reproduction" will be used, to include all seedlings, saplings, and smaller trees having high stump sprouting potential (Johnson 1993). It has been widely established that hardwood stumps decline in their probability for producing long-lived sprouts as their size increases (Sander and others 1984, Johnson 1993, Belli and others 1999, Golden 1999). A previous study of the sprouts originating on this site (Golden 1999) found that stumps from trees smaller than 12 inches dbh sprouted with high frequency, but those larger produced very few sprouts still alive three years after harvest. Consequently, all trees smaller than 12 inches dbh (including saplings and seedlings) tallied in the reproduction plots were included as advance reproduction. Small seedlings of water oak and willow oak were impossible to reliably distinguish, so all reproduction data for these two oaks will be treated as one class, "water/willow oak".

With all sizes taken together, advance reproduction (AR) of all commercial species combined averaged 12,572 per acre (table 2). Water/willow oak reproduction comprised the majority of these, averaging 7,594 per acre. Cherrybark oak was second in advance reproduction, at 1059 per acre. All other oaks combined averaged less than 100 per acre.

It is noteworthy that more than 95 percent of the advance reproduction for commercial species was less than 1 ft tall (small AR), with only 609 per acre taller than 1 ft (large AR) (table 2). For the oaks, only 0.5 percent (45 per acre) of their advance reproduction was taller than 1 ft. For the 952 reproduction plots, cherrybark oak averaged only 6 stems per acre more than 1 ft tall, with 4 per acre of these less than 3 ft tall. There were no cherrybark oaks found in the sizes taller than 3 ft but smaller than 5 inches dbh (table 2). Water/willow oak advance reproduction had somewhat more, but only 26 per acre in large AR, and all of these were less than 3 ft tall. Sweetgum and green ash each had more than 150 stems per acre in large AR, with the large majority of these less than 3 ft tall. Other commercial species, principally sugarberry and elms, comprised more than 230 large AR per acre (table 2).

The small number of large AR for the oaks was apparently due to the heavy shade at the seedling layer, which was created mostly by the midstory and understory layers. Small seedlings were able to establish from strong acorn crops, but failed to continue height growth once food reserves from the acorns were exhausted.

Tree Reproduction After Eight Years

Among the eight-year non-overtopped (NOT) reproduction, commercial tree species averaged 1174 stems per acre, with sweetgum the most abundant (422 per acre) and green ash (301 per acre) second (figure 1). Taken as a group, the oaks comprised about 29 percent (340 per acre) of the NOT reproduction, with water/willow oak having the highest numbers (242 per acre) (figure 1). Cherrybark oak was reduced to 85 NOT trees per acre, and the other oaks (swamp chestnut, shumard, and overcup) together averaged only 14 per acre.

Table 2—Advance reproduction, including all trees up to 12 inches dbh found in the reproduction plots, by size class

Size	Cherrybark Oak	Water/willow oak	Other oaks	Sweetgum	Green ash	Other commercial	Total commercial
				Trees/acre			
4" tall	480	2082	19	66	95	619	3361
>4"<12" tall	573	5486	64	83	503	1893	8602
>1'- 3' tall	4	26	7	112	153	153	453
3'- 10' tall	0	0	0	20	6	13	39
>10' tall - 5" dbh	0	0	4	18	3	50	75
>5"<12" dbh	2	0	2	21	0	17	42
Totals	1059	7594	96	320	760	2743	12572

Table 3—Comparison of oak advance reproduction density and stocking percentages (of 954 plots) to non-overtopped (NOT) reproduction eight years after harvest

Species	All AR	Large AR only	8 year NOT
	-----Stems/acre (pct. stocking)------		
Cherrybark oak	1112 (37)	6 (1)	85 (6)
Water/willow oak	7977 (56)	27 (2)	242 (14)
Other oaks	101 (7)	14 (1)	14 (1)
Sweetgum	336 (20)	180 (11)	422 (29)
Green ash	798 (34)	70 (12)	301 (21)
Other commercial	2882 (83)	243 (18)	110 (10)

Comparisons Of Preharvest To Eight-Year Species Composition

Advance Reproduction Comparison—In terms of number per acre, when all advance reproduction sizes are taken together, the attrition in numbers from AR to 8-year NOT was most dramatic for water/willow oak, which declined from 7977 to 242 per acre (table 3), for a 33:1 ratio of AR to 8-year stems. This is not surprising, since only 27 per acre of the AR stems were taller than 1 foot. Cherrybark oak numbers also declined drastically, from 1112 to 85 per acre (13:1). Even fewer (6 per acre) of its AR were taller than 1 foot. Only sweetgum showed an increase, from 336 to 422 per acre (table 3).

However, published predictive methods for oaks emphasize that larger AR, at least 1 foot tall, have much higher probabilities for reproduction success (Sander 1984, Johnson and Deen 1993, Belli and others 1999). If only those larger AR are considered, the oaks increased their numbers substantially – cherrybark oak from 6 to 85 per acre and water/willow oak from 27 to 242 per acre. This clearly indicates that large AR alone did not account for the majority of successful oak reproduction.

One of the most informative values in assessing reproduction success is stocking percentage. From the practical standpoint of comparing importance of a species among tree reproduction, distribution is perhaps as important as sheer numbers, since having a given number of widely distributed seedlings is a more advantageous situation than when they are concentrated in dense clusters.

Distribution is customarily assessed in silvicultural applications by determining the percentage of well-distributed sample plots that are "stocked". This gives information that is highly related to both density and distribution. For a specific species, a stocked milacre reproduction plot had at least one suitable individual of the species present. Stocking for "all AR" was determined using presence of any stem less than 12 inches as the criterion, but stocking using just "large AR" (that less than 1 ft tall excluded) was also determined.

With all sizes considered, AR stocking for cherrybark oak was somewhat low (37 percent), while water/willow oak was moderate (56 percent), and other oaks was very low (7 percent) (table 3). The stocking with large AR oaks was extremely low (1, 2, and 1 percent, respectively, for cherrybark, water/willow, and other oaks). When AR stocking was compared to that of 8-year NOT, the data exhibited a pattern similar to that for stems per acre, differing primarily in degree. The ratio of all AR stocking to 8-year was about 6:1 for cherrybark oak, 4:1 for water/willow oak, and 7:1 for other oaks (table 3). Unfortunately, the stocking levels were very low in the 8-year stand for the oaks, only 6, 14, and 1 percent for cherrybark, water/willow, and other oaks, respectively. Again, sweetgum exhibited an increase from preharvest to eight-year stocking (table 3). So, using plot stocking as the criterion, oak reproduction success would be judged to be very poor.

Preharvest Overstory Comparison—Another test of reproduction "success" for a specific species is whether it held its own or increased in proportion compared to its proportion in the preharvest overstory. In other words, has a species gained or lost in relative importance in the new stand compared to the harvested one?

When the species proportions in the preharvest overstory (all trees more than 5 inches dbh) numbers were compared to their proportions among the 8-year NOT trees (figure 2), the greatest gain achieved was for green ash, which increased more than fourfold, from 5 to 22 percent of stems. Water/willow oak gained slightly (13 up to 17 percent) and sweetgum remained almost the same (about 30 percent). However, cherrybark oak and other oaks lost substantially in proportions, dropping to less than half and to one-eighth, respectively (figure 2). Cherrybark oak comprised only 6 percent of the 8-year NOT trees, down from 14 percent in the preharvest overstory.

Table 4—Sources of plots stocked with non-overtopped oak reproduction after eight years

Source	Cherrybark oak	Water/willow oak	Other oaks
	———Number (pct.) of plots———		
All AR, <12" dbh	37 (62)	104 (78)	0 (0)
AR, 1' tall-12" dbh	2 (3)	8 (6)	4 (40)
Post-harvest germination	21 (35)	21 (16)	6 (60)
Totals	60(100)	133(100)	10(100)

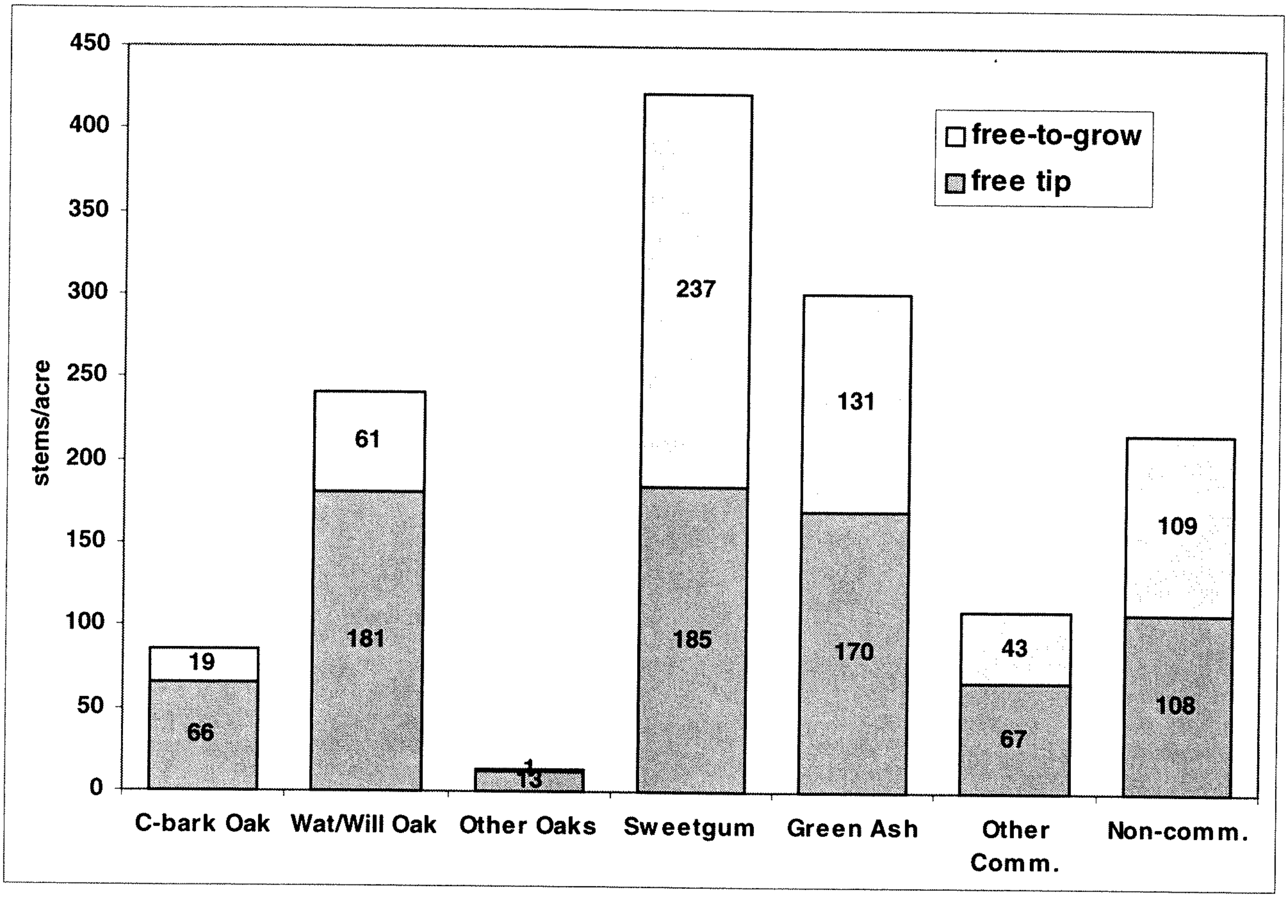


Figure 1—Eight-year non-overtopped (NOT) reproduction.

Origins Of Eight-Year Oak Stocking

Since it was obvious from the previous analyses that most of the successful (non-overtopped) oak regeneration at eight years could not have come from large advance reproduction, where did it come from? Conventional wisdom is that oak regeneration must come almost entirely from advance reproduction, and so postharvest germination of seed plays little or no role (Johnson 1993). Although individual seedlings were not tagged in this study, the careful inventory of precisely relocated small plots allowed me to develop some conservative assessments of the role of post-harvest germination (PHG) in providing successful stocking at eight years.

For this, I examined for each oak species just those plots that were stocked with at least one NOT tree at the eight-year inventory. For these, if a plot had not been stocked with any size AR, it was assumed that the source of that plot's stocking at 8 years was PHG. If it had any AR, the stocking was assumed to have originated from that. For those stocked plots that had contained AR, they were assumed to have originated from large AR if any stems taller than 1 foot were present for the species at the preharvest inventory. Otherwise, they were assumed to have originated from small AR, less than 1 foot tall. Thus this approach produced estimates of PHG and small AR that are minimums relative to AR and large AR, respectively.

The results indicate that PHG contributed substantially to the eight-year NOT stocking for the oaks. For cherrybark oak, 35 percent of its stocking (21 of 60 plots) was from post-harvest germination (table 4). The proportion was smaller for water/willow oak, 17 percent, but still substantial. Only 10 plots were stocked with other oaks, but 6 of these were from PHG.

Most of the stocking for cherrybark and water/willow oaks originated from small advance reproduction, comprising 62 and 78 percent, respectively, of stocked plots (table 4). Only about 3 and 6 percent of the stocking originated from AR taller than 1 foot for cherrybark and water/willow oaks respectively. This is primarily a reflection of the lack of large advance reproduction in the stand.

Major Limitations To Successful Reproduction

Muscadine grape (*Vitis rotundifolia*) proved to be a major problem on this site. It did not appear to be particularly abundant before the harvest, although vines were common and small seedlings were scattered throughout. Between the three-year assessment (not reported) and the eight-year inventory, a large number of seedlings and saplings were completely covered by grapevines, and many were bent or even broken over by the weight of the heavy vines. Rattan-vine (*Berchemia scandens*) also covered and broke seedlings in some areas. Erect blackberries (*Rubus* spp.) formed tall, dense thickets in

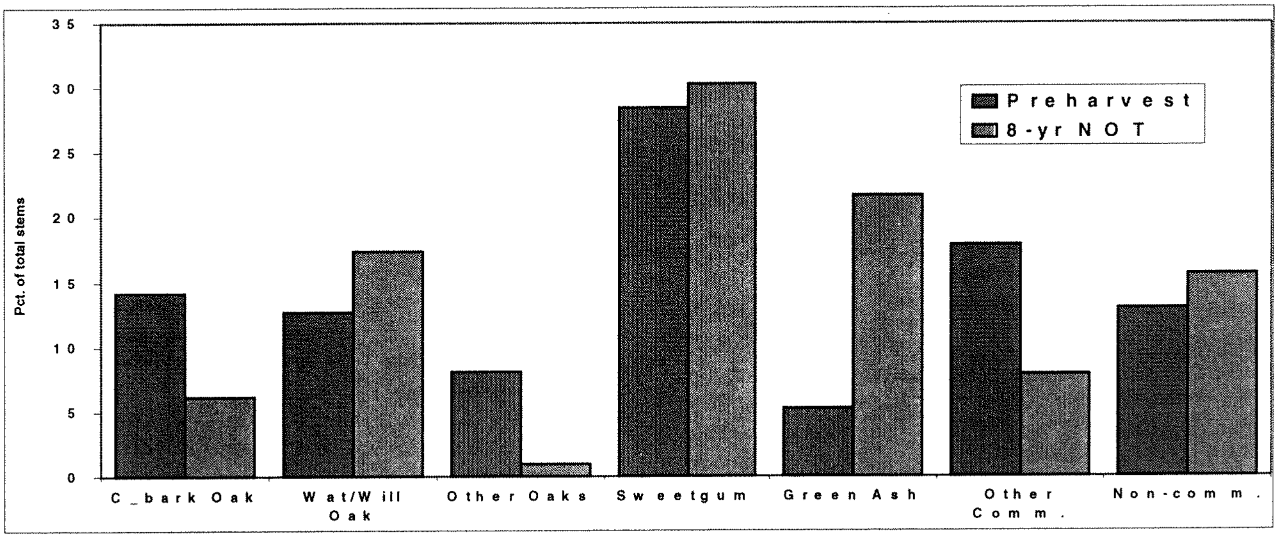


Figure 2—Percentage of total stems, by species, for preharvest trees (>5" dbh) vs 8-year non-overtopped.

some areas. Some of these created sufficient shade to cause mortality of developing oaks. The blackberries also provided support for the woody vines, producing a tent-like effect in some areas.

CONCLUSIONS

Eight years after harvesting small clearcut patches in a riverbottom mixed forest, there was adequate reproduction of commercial tree species overall (1174 per acre), but there were some scattered unstocked areas. The overall reproduction of oaks was relatively poor (340 per acre and less than 20 percent milacre plot stocking) and cherrybark, Shumard, and swamp chestnut oak reproduction was probably not sufficient to recover their proportions that existed in the preharvest overstory. Water/willow oaks were more successful than the other oaks and may attain equal or higher levels in the future stand compared to the preharvest overstory. Understocked areas in the patches resulted primarily from development of heavy woody vine and shrub cover, with grapevine the most important problem. The eight-year stocking of oaks originated primarily from advance reproduction less than one foot tall and from post harvest germination of acorns. The contribution of large advance oak reproduction was very small, due to the very low numbers present before harvest.

REFERENCES

Belli, K.L.; Hart, C.P.; Hodges, J.D.; Stanturf, J.D. 1999. Assessment of the regeneration potential of red oaks and ash on minor bottoms of Mississippi. Southern Journal of Applied Forestry 23(3): 133-138.

Clatterbuck, W.K.; Hodges, J.D. 1988. Development of cherrybark oak and sweetgum in mixed, even-aged bottomland stands in central Mississippi, USA. Canadian Journal of Forest Research 18(1): 12-18.

Golden, M.S. 1999. Factors affecting sprouting success in a bottomland mixed hardwoods forest. In: Haywood, J.D., ed. Proceedings of the tenth biennial southern silvicultural research conference; 1999 Feb. 16-18; Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 157-161.

Hodgkins, E.J.; Golden, M.S.; Miller, W.F. 1979. Forest habitat regions and types on a photomorphic-physiographic basis: a guide to forest site classification in Alabama-Mississippi. Southern Cooperative Ser. Bull. 210. Auburn, AL: Auburn University, Alabama Agricultural Experiment Station. 64 p.

Johnson, P.S. 1993. Sources of oak reproduction.. In: Loftis, D.L.; McGee, C.E. eds. Oak regeneration: serious problems, practical recommendations. Symposium proceedings; 1992 Sept. 8-10, Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 112-131.

Johnson, R.L.; Deen, R.T. 1993. Prediction of oak regeneration in bottomland forests. In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: serious problems, practical recommendations. Symposium proceedings; 1992 Sept. 8-10, Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 146-155.

Sander, I.L.; Johnson, P.S.; Rogers, R. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. Res. Pap. NC-251. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 16 p.

THE USE OF SOIL SCARIFICATION TO ENHANCE OAK REGENERATION IN A MIXED-OAK BOTTOMLAND FOREST OF SOUTHERN ILLINOIS

John M. Lhotka and James J. Zaczek[1]

Abstract—The purpose of the study was to investigate whether soil scarification following seed fall can be used to increase the density of oak regeneration in a mixed-oak stand. The study area was a 4.5-hectare stand dominated by cherrybark oak (*Quercus pagoda* Ell.). The understory had a high percent cover of poison ivy (*Toxicodendron radicans* (L.) Kuntze) and essentially lacked oak advance regeneration. In November 1999, the scarification treatment was accomplished using a tractor with a pull-behind field disk. One growing season after scarification, the number of oak seedlings was significantly higher in scarified plots (7,243/ha) than in the control plots (453/ha). Percent cover of poison ivy decreased from 36 percent to12 percent in the scarified plots. These results suggest that, in the presence of abundant acorns, scarification increased the likelihood of oak germination in a stand that lacked advanced oak regeneration prior to the treatment. Finally, because scarification increased the density of oak seedlings, it will increase the likelihood that mixed-oak stands can be successfully regenerated after a canopy disturbance.

INTRODUCTION

It is well documented that in order to regenerate oak stands a sufficient amount of competitive advance regeneration must be present before a harvest (Crow 1988, Johnson and others 1989, Meadows and Stanturf 1997, Zaczek and others 1997, Larsen and Johnson 1998). Understory treatments such as mechanical removal and chemical control of competition have been proposed to increase oak establishment and growth in bottomland oak forests (Crow 1988, Johnson and others 1989, Loftis 1990, Nowacki and others 1990, Bundy and others 1991, Nowacki and Abrams 1992, Zaczek and others 1997). Soil scarification is one other treatment that has been proposed (Scholz 1959, Bundy and others 1984, Crow 1988, Johnson and others 1989, Barry and Nix 1992, Zaczek and others 1997). Soil scarification may help to provide favorable germination conditions for acorns, protection from predators, and control competition (Crow 1988, Zaczek and others 1997) and therefore increase the likelihood of germination and development into a vigorous seedling.

Soil scarification may increase acorn germination and survival by incorporating the acorns into the soil (Zaczek and others 1997, Lhotka 2001). Acorn germination conditions have been shown to be more favorable below the soil surface than on the soil surface (Griffen 1971, Janzen 1971). In addition, acorns buried below the surface have been shown to be less susceptible to animal damage (Auchmoody and others 1994, Nilsson and others 1996). It is important to provide this protection because of high acorn predation rates (Auchmoody and others 1994, Steiner 1995). Because scarification helps to incorporate acorns below the surface, it may increase the chances that an acorn will germinate and develop into a vigorous seedling. Scarification may also help control competing vegetation. With a decrease in competing vegetation, newly established seedlings may gain a better competitive position and have an increased chance for successful development.

The purpose of the study was to investigate whether soil scarification, in the presence of abundant acorns, can be used to enhance oak regeneration in a mixed-oak bottomland forest. This paper reports the germination and survival of oak regeneration one year after soil scarification.

METHODOLOGY

The study was conducted in a 4.5-hectare mixed oak-hickory bottomland forest stand located in Saline County, Illinois. The overstory was composed of cherrybark oak (*Quercus pagoda* Ell.), shagbark hickory (*Carya ovata* [Mill.] K. Koch), mockernut hickory (*Carya tomentosa* [Poir.] Nutt.), and post oak (*Quercus stellata* Wang.). The understory was dominated by a thick blanket of poison ivy (*Toxicodendron radicans* [L.] Kuntze) and essentially lacked advanced oak reproduction.

Prior to scarification, eight linear transects to receive scarification were laid out within the stand. A total of fifty 1.77 m^2 plots were located along the center of the transects to measure existing vegetation. An additional fifty 1 m quadrats were located along the transects to measure the number of acorns and hickory nuts present prior to treatment. Unscarified control plots were paired with each scarified plot and were located 3.8 m from the center of the scarified transects (figure 1). The plots were allocated proportionally according to the length of the transect. All trees < 1.5 m in height were measured to the nearest 0.1 m. Percent cover of vine and shrub species were also

[1]Graduate Research Assistant and Assistant Professor; Department of Forestry, Southern Illinois University at Carbondale; Carbondale, IL 62901

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—The density (number per ha) of viable seeds by treatment and species group

Species	Density of Viable Seeds Control	Density of Viable Seeds Scarified
All Oaks[a]	47,466	56,399
Hickory[b]	932	1,598

[a] All Oaks include: *Quercus bicolor* Willd., *Quercus michauxii* Nutt., *Quercus macrocarpa* Michx., *Quercus pagoda* Ell., *Quercus stellata* Wang.
[b] Hickory includes: *Carya ovata* (Mill.) K. Koch., *Carya tomentosa* (Poir.) Nutt.

measured at that time. The acorn crop was measured by using 1 m^2 plots placed directly adjacent to the center of each vegetation plot. At each acorn plot, acorns were tallied by species and a sample was collected to test for germination success.

Scarification was completed on November 5, 1999 using an International 464 tractor with an International 122 disk. The disk was approximately 2.44-meters wide. This International 122 is a standard-type field implement with rolling metal disks that help to penetrate the soil and mix the upper soil layer. Because the ground was very dry, the area was scarified by making three passes across the transects with the disk. The paired control plots were left undisturbed.

The overstory inventory was conducted in May 2000 using twenty 7.98 m radius plots. All trees >1.5 m in height and <9 cm DBH were measured. A relative importance value was then calculated for each species (Cottam and Curtis 1956). At each overstory plot,a 25 m^2 plot was used to measure all trees <1.5 m in height and less than 9 cm at DBH.

Table 2—Tree Seedlings densities (stems per ha) by species, inventory date, and treatment

Species	Pretreatment Stems per ha Control	Pretreatment Stems per ha Scarified	October 2000 Stems per ha Control	October 2000 Stems per ha Scarified
All Oaks[a]	566	453	453	7,243*
Acceptable Hardwoods[b]	3,778	5,206	4,640	10,072*

*indicates significant difference between treatments at alpha = 0.05
[a] All Oaks include: *Quercus pagoda* Ell., *Quercus stellata* Wang.
[b] Acceptable Hardwoods include: *Carya ovata* (Mill.) K. Koch., *Carya tomentosa* (Poir.) Nutt., *Cornus racemosa* Lam., *Diospyros virginiana* L., *Fraxinus pennsylvanica* Marsh., *Ulmus americana* L.)(American elm), red elm, (*Liquidambar styraciflua* L., *Nyssa sylvatica* Marsh.) *Prunus serotina* Ehrh., Sassafras albidum (Nutt.) Nees, *Ulmus alata* Mic

In October 2000, understory vegetation was measured along transects using fifty randomly located 1.77 m^2 radius paired plots to reflect first year survival. The number of stems was summarized into four species groups (All Oaks, Acceptable Hardwoods, Total Tree Seedlings, and Poison Ivy). The pretreatment acorn number and regeneration density by species for each inventory were analyzed by using one-way analysis of variance (ANOVA) at an alpha = 0.05 to test for differences between the control and scarified treatments.

RESULTS

The stand had a mixed bottomland oak-hickory composition with a basal area of 28 m^2/ ha and a density of 365 stems / ha. The dominant overstory species were cherrybark oak, shagbark hickory, mockernut hickory, and post oak. Other species did not exceed 2.0 in importance value. The stand had a very sparse midstory canopy

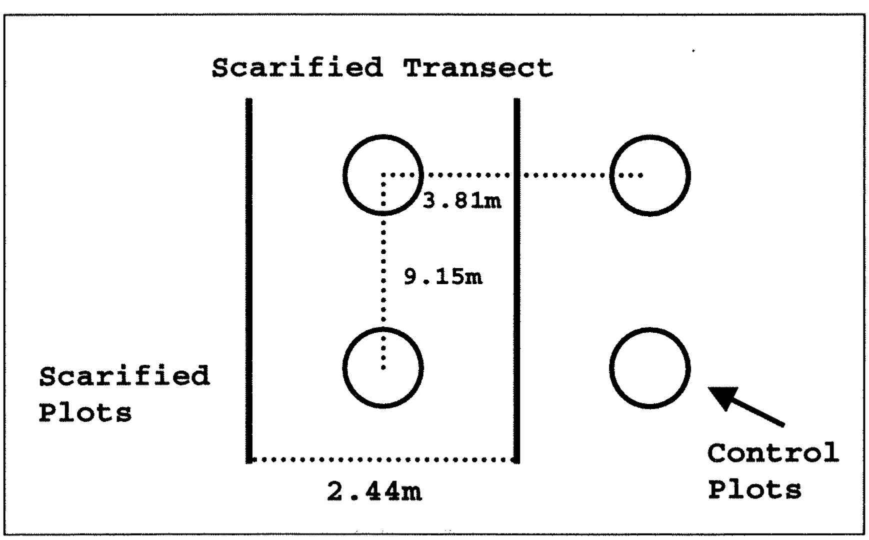


Figure 1—Paired plot sampling design for understory vegetation inventory

stratum and was comprised of only 280 total stems/ha. Of these stems, 57 percent were green ash (*Fraxinus pennsylvanica* Marsh.) and 21 percent were hickories (*Carya spp.*).

The prescarification vegetation inventories and acorn counts showed no significant difference between the control and scarified plots. The number of acorns (F = 0.50, p = 0.4792, df = 1,99) (table 1) and the number of total seedlings (F = 0.25, p = 0.6167, df = 1,99) were not significantly different between the control and scarified plots (table 2). The number of acceptable hardwoods in the scarified plots was also not significantly different (F = 0.36, p = 0.5506, df = 1,99) than the number in the control. The height distribution prior to treatment was spread across all height classes, but an increased frequency occurred in the classes shorter than 85cm. Also in the understory, the poison ivy cover was also not significantly different (F = 0.10, p = 0.7570, df = 1,99) between the control and scarified plots.

One year after treatment, the scarified plots had a higher seedling density than the control (table 2). The oaks, especially, had higher densities in the scarified plots. This large increase in oak in the scarified plots was related to increased germination rates. The germination percentage of viable acorns found in the scarified plots was 9 percent, while in the control plots the percent germination was near zero. As a result of the new germinants, the number of oaks was significantly higher (F = 14.96, p = 0.0002, df = 1,99) in the scarified plots than in the control plots. In addition, the number of acceptable hardwood species was significantly higher in the scarified plots. One year after treatment, the oaks composed 42 percent of all seedlings in the scarified plots, but only made up 9 percent of all seedling in the control. Unlike tree seedling density, the percent cover of poison ivy was significantly lower (F = 26.43, p = 0.0001, df = 1.99) in the scarified plots (12 percent) than in the control plots (36 percent).

Scarified plots also had fewer large seedlings than the control plots. In the control plots, 1,697 stems / ha occupied the height classes > 44 cm and 2,490 stems / ha were present in the lower two height classes (0-24 cm, 25-44 cm) and these stems were mostly green ash. Oaks only accounted for 14 percent of the total stems in the lower two height classes and only 7 percent of the total stems > 44 cm in height in the control plots. Unlike the control plots, the scarified plots only had 339 stems/ha (2 percent of total) present in the height classes greater than 44 cm. Ninety-eight percent of the seedlings in the scarified plots were less than 44 cm in height and 86 percent of the total stems are less than 25 cm in height. In the scarified plots, oaks accounted for 48 percent of all species in the 0-24 cm height class and no oaks are greater than 24 cm in height.

DISCUSSION

The scarification apparently enhanced acorn germination even under severe predation pressure. Of the potentially viable acorns remaining at the time of scarification, the germination percentage in the scarified plots was 9 percent, while the control plots had no new germinants. Although the germination percentage in the scarified plots was somewhat low, even a small increase in germination percentage resulted in greatly increased numbers of oak recruits and the overall pool of advanced regeneration.

Past soil scarification research had similar early results to this study. A project conducted by Scholz (1959) used a disking method to improve the initial establishment of northern red oak. After the first year, the study showed an increase in northern red oak densities in the disk plots. In addition, a study conducted by Zaczek and others in 1997 found that higher proportions of acorns germinated in the scarified plots (28 percent) than in the control plots (2 percent). In addition, a significantly greater number of northern red oak and a lower number of red maple were found on the scarified plots when compared to the control plots. The current study had similar trends to what was initially found in the aforementioned studies, but the current study's acorn germination percentages were not as high as found in Zaczek and others (1997). However, it is difficult to strictly compare the studies because they were not conducted in same region, the same species were not involved, predation pressure varied, and the stands did not have the same environmental conditions.

In addition to enhancing germination, the scarification treatment also played a role in reducing the poison ivy cover in the understory. The reduced competition should free up resources necessary for enhanced oak seedling growth.

The results after one year of this study look promising. The understory condition was more favorable than prior to scarification as scarified plots had more oak advanced regeneration present. With regard to seedling height distribution, it also appeared the oaks made up a favorable proportion of the regeneration cohort present one year after scarification. Because oak made up a more favorable proportion of the stems in the understory and did not have an over abundance of larger seedlings to compete with, the stand was in a better condition to be regenerated. One well accepted guideline about regenerating oak is that to ensure success large competitive advanced regeneration must be present in the understory prior to harvest (Crow 1988, Johnson and others 1989, Meadows and Stanturf 1997, Zaczek and others 1997, Larsen and Johnson 1998). It appears that the scarification has resulted in greater numbers of oak seedlings in an enhanced competitive position.

However, the oak seedlings present in the understory do not guarantee successful regeneration. Many factors are important to consider to ensure the future development of the regeneration currently present in the understory. An important factor controlling the survival of these seedlings is the understory light levels (Crow 1988, Nowacki and Abrams 1992) as cherrybark oak and post oak are intolerant of shade (Krinard 1990, Stransky 1990). Competing vegetation may also play a role in impacting the growth of the newly establish oak seedling reproduction. If oak growth is not rapid enough to extend above the competition, a regrowth of poison ivy over time may retard the development of these newly established seedlings. Likewise, repeated deer browsing may have a negative impact on these newly established seedlings (Lorimer 1993).

We suggest that manipulation of the midstory or overstory is likely necessary to alleviate some of the problems created by low light levels (Janzen and Hodges 1985, Loftis 1990). Without a release, the seedlings present will most likely not survive and leaving the stand in a condition similar to what was seen prior to the scarification treatment. However, even a release treatment does not guarantee the survival of this newly established regeneration cohort.

CONCLUSIONS

The purpose of this study was to determine the effects of shallow soil scarification, in the presence of abundant acorns, on the germination and first year survival in a mixed-oak bottomland forest. One year after treatment, the number of oaks was significantly greater in the scarified plots than in the control plots. The results suggest that the soil scarification treatment method used created more favorable conditions for increased acorn germination and oak seedling survival. The results gained from this study not only extend the knowledge of soil scarification as a tool to enhancing oak seedling reproduction, but also suggest that this silvicultural treatment may be a useful management tool when applied in bottomland oak stands.

ACKNOWLEDGMENTS

The authors would like to thank Kenneth Youngs and Don Van Ormer for their support with project. In addition, we would like to thank John Groninger for his editorial comments in reviewing this manuscript.

REFERENCES

Auchmoody, L.R.; H.C. Smith; R.S. Walters. 1994. Planting northern red oak acorns: Is size and planting depth important? For. Ser. Res. Pap. NE-693. Radnor, PA: U.S. Department of Agriculture, Northeastern Forest Experiment Station. 5 p.

Barry, J. E.; L. E. Nix. 1993. Impact of harvesting activities on oak seedling establishment in a bottomland hardwood forest. In: J.C. Brissette, ed. Proceedings of seventh biennial southern silvicultural research conference. Gen. Tech. Rep. SO-093. New Orleans, LA: U.S. Department of Agriculture, Southern Forest Experiment Station: 155-159.

Bundy, P.P.; A.A. Alvin; M.J. Baughman. 1991. Red oak regeneration following "scarification" and harvesting: A case study. Northern Journal of Applied Forestry. 8: 173-174.

Cottam, W.; J. T. Curtis. 1956. The use of distance measures in phytosociological sampling. Ecology 37: 451-460.

Crow, T.R. 1988. Reproductive mode and mechanisms for self-replacement of northern red oak (*Quercus rubra*)-A review. Forest Science. 34(1): 19-40.

Griffen, J.R. 1971. Oak regeneration in the upper Carmel Valley, California. Ecology 52: 862-868.

Janzen, D.H. 1971. Seed predation by animals. Ann. Rev. Ecol. Syst. 2: 465-492.

Janzen, G.C.; J. D. Hodges. 1985. Influence of midstory and understory vegetation removal on the establishment and development of oak regeneration. In: E. Sholders, ed. Proceedings third biennial southern silvicultural research conference. Gen. Tech. Rep. SO-054. New Orleans, LA: U.S. Department of Agriculture, Southern Forest Experiment Station: 273-278.

Johnson, P.S.; R.D. Jacobs; A.J. Martin; E.D. Godel. 1989. Regenerating northern red oak: Three successful case histories. Northern Journal of Applied Forestry. 6: 174-178.

Krinard, R.M. 1990. Cherrybark Oak. In: R.M. Burns and B.H. Honkala, eds. Silvics of North America: Volume 2, Hardwoods. Agriculture Handbook 654. Washington, D.C.: U.S. Department of Agriculture, Forest Service: 644-649.

Larsen, D.R.; and P.S. Johnson. 1998. Linking the ecology of natural oak regeneration to silviculture. Forest Ecology and Management. 106: 1-7.

Lhotka, J.M. 2001. The effects of soil scarification on oak regeneration in upland and bottomland forests of southern Illinois. Carbondale, IL: Department of Forestry, Southern Illinois University. 92p. M.S. Thesis.

Loftis, D.L. 1990. A shelterwood method for the regenerating red oak in the Southern Appalachians. Forest Science. 36(4): 917-929.

Lorimer, C.G. 1993. Causes of the oak regeneration problem. In: D.L. Loftis and C.E. McGee, eds. Oak regeneration: Serious problems and practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Southeastern Forest Experiment Station: 14-39.

Meadows, J. S.; J. A. Stanturf. 1997. Silvicultural systems for southern bottomland hardwood forests. Forest Ecology and Management 90: 127-140.

Nowacki, G.J.; M.D. Abrams. 1992. Community, edaphic, and historical analysis of mixed oak forests of the Ridge and Valley Province in Central Pennsylvania. Canadian Journal of Forest Research. 22: 790-800.

Nowacki, G.J.; M.D. Abrams; C.G. Lorimer. 1990. Composition, structure, and historical development of northern red oak stands along an edaphic gradient in North-Central Wisconsin. Forest Science. 36(2): 276-292.

Scholz, H. F. 1959. Further observations on seedbed scarification show benefits to northern red oak were temporary. Technical Notes No. 555. St. Paul, MN: U.S. Department of Agriculture, Lake States Forest Experiment Station. 2 p.

Steiner, K.C. 1995. Autumn predation of northern red oak seed crops. In: K.W. Gottschalk and S.L.C. Fosbroke, eds. Proceedings, 10th Central Hardwood Forest Conference; 1995 March 5-8; Morgantown WV. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Northeastern Forest Experiment Station: 489-494.

Stransky, J.J. 1990. Post Oak. In: R.M. Burns and B.H. Honkala, eds. Silvics of North America: Volume 2, Hardwoods. Agriculture Handbook 654. Washington, D.C.: U.S. Department of Agriculture, Forest Service:738-743.

Zaczek, J. J.; J. Harding; J. Welfley. 1997. Impact of soil scarification on the composition of regeneration and species diversity in an oak shelterwood. In: S.G. Pallardy; R.A. Cecich; H.G. Garrett; and P.S. Johnson, eds. Proceedings, 11th central hardwood forest conference. Gen. Tech. Rep. NC-188. St. Paul, MN: U.S. Department of Agriculture, North Central Forest Experiment Station: 341-348.

PREPLANTING SITE TREATMENTS AND NATURAL INVASION OF TREE SPECIES ONTO FORMER AGRICULTURAL FIELDS AT THE TENSAS RIVER NATIONAL WILDLIFE REFUGE, LOUISIANA

John W. McCoy, Bobby D. Keeland, Brian Roy Lockhart, and Thomas Dean[1]

Abstract—As part of a study of oak planting techniques for bottomland hardwood afforestation we examined the natural invasion of woody species onto former agricultural fields at Tensas River National Wildlife Refuge. Three replications of 14 treatments were established as 0.4 hectare (1 acre) plots in a complete randomized block design. Combinations of these treatments were used to examine the effects of disking and distance from existing forest edges on natural invasions of woody species. Each one-acre plot was sampled with 4 subplots, 100 m^2 each, for all seedlings greater than 0.3 meters in height. A total of 18 woody species, dominated by elm(*Ulmus* sp.) (41 percent), ash(*Fraxinus pennsylvatica*) (25 percent), and sugarberry(*Celtis laevigata*) (21 percent), and with lower frequencies of honey locust(*Gleditsia tricanthos*), deciduous holly(*Ilex decidua*), persimmon(*Diospyros virginiana*), hawthorn(*Crataegus* sp.), sweetgum(*Liquidambar styriciflua*), and black willow(*Salix nigra*), were noted. The treatment with little or no disturbance, no till, had more individuals (814.6/ha or 325.8/ac) than the strip disked(SD)(643.7/ha or 257.5/ac) or disked(DD)(380.2/ha or 152.1/ac) treatments. These differences in invasion rates may have been related to several aspects of disking. Disking may eliminate existing agricultural rows and furrows reducing microtopographic variation, bury seeds too deeply, or expose seeds to drying. Distance from the forest edge also affected invasion rates with an average of 1038.8 individuals per ha (415.5/ac) between 129 - 259m, 635.1/ha (254.0/ac) between 260 - 406 m, and 301.3/ha (120.5/ac) at greater than 406 m. The nearest mature forest edge was 129 m distant. Woody invaders were found up to 640 m from the nearest forest edge. Although factors such as soil type, herbivory, and moisture influence the woody plant species found in these fields, initial disturbance and distance from the forest edge was shown to be important factors determining natural invasion success.

INTRODUCTION

Reestablishment of bottomland hardwood (BLH) forests throughout the Lower Mississippi River Valley (LMRV) has increased in the last 10 years. Interest in replanting BLH forests to agricultural fields arises from increased land availability associated with decreased farm products income and the understanding that only a small amount (2.8 million ha) of historical (10 million ha) bottomland hardwoods remain in the LMRV (National Research Council 1982; Hefner & Brown 1985). Over the past 10 years 77,698 hectares were planted to BLH species in Arkansas, Louisiana and Mississippi by the U.S. Fish & Wildlife Service, the U.S. Army Corps of Engineers, the Natural Resources Conservation Service, the Arkansas Game and Fish Commission, the Louisiana Department of Wildlife and Fisheries and the Mississippi Department of Wildlife Fisheries and Parks. More land (89,009 ha) is expected to be planted over the next five years by these same agencies (King and Keeland 1999).

Initially the main focus of these plantings was the establishment of hard mast species such as oaks and pecan with the expectation that light seeded species would invade naturally. Most stands were reforested to provide habitat for game species, but recently, land managers have realized that maintaining a diverse plant community is important to mammals and birds that live all or part of their lives in bottomland hardwoods (Daniel and Fleet, 1999). This realization has shifted the focus of reforestation efforts to include the planting of many additional tree species such as ash, sugarberry, sweetgum and baldcypress (King and Keeland 1999). But, the role that natural invasion will provide for increased diversity and structural complexity remains to be understood. Questions as to the extent that natural invasion can be counted on to provide additional species and increase the tree diversity and structural complexity of the developing stands remain unanswered.

[1]General Biologist and Research Ecologist, USGS, National Wetlands Research Center, Lafayette, LA; Associate Professor and Associate Professor, School of Forestry, Wildlife and Fisheries, Louisiana State University, Baton Rouge, LA, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

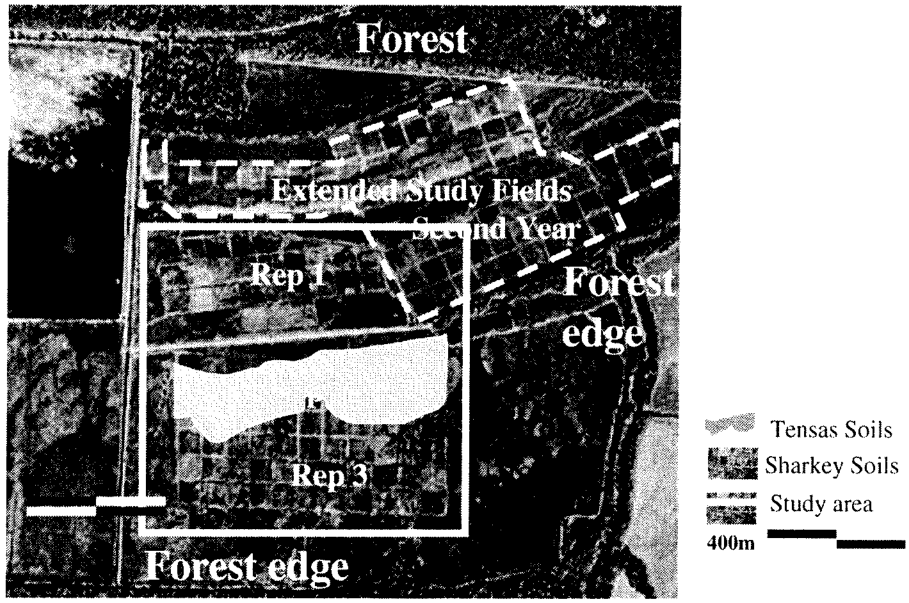


Figure 1—Photograph of the Tensas River NWR study area (1995) showing the one-acre plots outlined by 10 m wide buffer strips. Forest edges for possible sources of seedlings are noted. Extended study fields are are part of a subsequent year study that are yet to be counted. North is to the top of the photograph.

In 1993 a reforestation study was jointly developed between the U.S. Fish & Wildlife Service, the Louisiana Department of Wildlife & Fisheries and the School of Forestry, Wildlife and Fisheries at Louisiana State University. The purpose of the study was to examine the establishment, survival and growth responses of selected oak species to several planting techniques. Over time additional woody species invaded the study plots and provided another aspect to the study. The purpose of this portion of the overall study is to examine the natural invasion of woody species onto these reforested areas to determine if the planting techniques (for the oaks) affected invasion rates.

METHODS

The study was conducted on the Tensas River National Wildlife Refuge (Tensas NWR) in northeastern Louisiana. The only topographic relief on the site consists of an old levee of the Tensas River. The levee runs east/west through the study area and is about 1 to 3 meters higher than the surrounding floodplain. Tensas soils, very deep, somewhat poorly drained, very slowly permeable, are found on the levee while Sharkey clay soils, very deep, poorly and very poorly drained, very slowly permeable, are found on the surrounding floodplain. The study area, which was fallow for less than one year before planting, was divided into one acre study plots (figure 1). Treatments were assigned as a randomized complete block design involving six direct seeding treatments as follows: (1) double disk, maximerge direct seed (DD); (2) double disk, maximerge direct seed, roll (DR); (3) strip disk, maximerge direct seed (SD); (4) no till, maximerge direct seed (NT); (5) single disk, cyclone direct seed, single disk (CS); (6) single disk, cyclone direct seed, single disk, roll (CR). The plots were direct seeded during the fall (October 1993) and spring (March 1994). Two oak species were planted, Nuttall (*Quercus texana*) and water oaks (*Q. nigra*), with one species per plot.

Two additional treatments (hand and machine planting of bare-root seedlings) were initiated December 1993. Each of the 14 treatments was replicated three times for each species producing a total of 84 treatment plots.

Fields were not bushhogged, but disking for selected treatments was accomplished in September 1993. Fall treatments were planted in October and spring treatments were planted in March 1994. All post-planting disking associated with cyclone direct seeding was accomplished immediately after planting. Seed and seedlings were kept chilled before planting (personal communication John Simpson, USFWS Tensas River NWR).

Each of the 84 one-acre study plots was sampled during November 1999 using 4 circular subplots, 100 m^2 each, established 20 m in toward the center from the corners of each field. All woody species greater than 0.3m in height was tallied from each subplot. Saplings were categorized by height into the following classes: (1) > 0.3 to < 0.5 m, (2) > 0.5 to < 1.0 m, (3) > 1.0 to < 1.4 m, (4) > 1.4 meters to < 2.5 cm diameter at breast height (DBH, at 1.4 m) and (5) all trees > 2.54 cm DBH. Diameters were recorded only for those trees greater than 2.5 cm DBH.

Data on other woody perennial species such as *Sabal minor* (palmetto) was noted during the sampling. The dominant herbaceous species were noted for each plot, but a complete census of the herbaceous vegetation was not attempted. Data were analyzed by ANOVA using JMP (SAS 1988).

RESULTS AND DISCUSSION

Species Summary

A total of 4,496 individuals of 18 woody plant species, including the oaks, was observed on the plots (table 1). Average stem density across all plots was 541.9/ha (219.4 /ac) for invaders and 781.6/ha (316.4 /ac) for planted oaks. The presence of Nuttall oak, water oak on some plots where these species were not planted, and the presence of some willow oak (*Q. phellos*) on more than half the subplots suggests a possibility of acorn or seedling contamination at the time of planting. Willow oak was not one of the oak components.

Exclusive of the oaks, 1,821 stems were counted in all subplots, with three species groups dominating; elms (*Ulmus alata, U. Americana, and U. crassifolia*, 231.8/ha), ashes (*Fraxinus pennsylvatica,* 132.4/ha), and sugarberry (*Celtis laevigata,* 109.5/ha). These three species accounted for 85.1 percent of all naturally invading saplings encountered in the study. Frequency on subplots were 90.5, 61.9, and 86.9 percents for elm, ash, and sugarberry, respectively. These data show that not only were elms, ash, and sugarberry the most numerous species, but that they occurred on the greatest proportion of the plots. Elms and sugarberry were the most ubiquitous. Honey locust (*Gleditsia tricanthos*) and deciduous holly (*Ilex decidua*) was also common, occurring on 30 and 36 percent of the plots, respectively. Although most species were fairly evenly distributed among and within plots, two species, hawthorns (*Crataegus* sp.), and persimmons (*Diospyros virginiana*), exhibited clumped distributions. Sugarberry occurred in 47 percent of the plots and in 25 percent of the subplots as the only woody invader species. In general, those plots with sugarberry as the only woody invader were the furthest plots from the nearest forest edge. Elms occur in 72 percent of all subplots but never occurred without other tree species within a subplot. These occurrences are linked to distance but are also to related to soil type and herbaceous communities. Many of the dominant herbaceous plants act as perches for small songbirds and as such may help promote increased woody species density and diversity. These same herbaceous plants may also act as cover for rodents that feed on the seeds and seedlings.

Species Diversity

A total of 18 woody plant species invaded onto the study plots. The number of species may have been greater, but, due to the number of volunteers helping on the project, no attempt was made to identity hawthorns, or wild cherry to species. In addition, 31 elm saplings were listed as elm sp. on the data sheets. Forty two percent of the species, including boxelder, red maple, swamp dogwood, sweetgum, swamp cottonwood, saltbush, water hickory, and wild cherry make up only 3.6 percent of the saplings counted. The most abundant species, sugarberry, ash, and elms, make up 82.1 percent of the total number of individuals counted but are only 22.2 percent of the individual species represented within this study.

On average, 541.9 saplings/ha (219.4 /ac) were counted on the subplots. Twelve percent of all subplots at greater than 335 m from a forest edge did not have any invaders, but none of the one-acre plots were lacking natural invaders. In a previous study, where all tree seedlings were recorded, several 100 m^2 plots were empty (Allen and others, 1998). The proximity of these fields to a forest edge was a stronger influence on natural invasion rates than treatment effects ($p < .0001$). Several seedlings less than 30 cm were observed on many plots but were not counted as part of this study. It is probably that many more seedlings less than 30 cm tall were present but not counted.

All species encountered in this study, excluding the Prunus spp., are facultative to obligate wetland plants. Survival and growth of some species may have been affected by much less than average rainfall during the growing seasons of 1998 and 1999.

Herbaceous Vegetation

The herbaceous layer generally consisted of a mixture of herbs, grasses and vines similar to that reported by Allen and others, (1998). Most plots were dominated by one species or a combination of two to four species. Dominant herbaceous vegetation included *Solidago* sp. (24.0 percent relative frequency), *Lythrum salicare* (21.3 percent), *Campsis radicans* (12.7 percent), *Sorgham halapense* (8.0 percent), and *Andropogon glomeratus* (7.14 percent). Several other relatively uncommon species noted on the plots included *Eupatorium* spp., *Verbena brasilensis*, and Aster spp. *Lythrum salicare* was the only observed species considered to be a noxious weed (Kartez, 1999).

Although some plants common to very wet areas, such as *Iva annua* and *Juncus effusis*, were found on the plots, their abundance may have been much less than is normal for this area. The drought of 1998 and 1999 (figure 2) caused many wet areas to dry out completely and probably had an impact on the herbaceous vegetation. It is possible that wet-site species may have been more abundant if the study has been conducted during a wetter time.

Although many areas were dominated by dense mats of vines such as *Rubus* sp., *Campsis radicans* and *Smilax* sp., these mats were generally small when compared with the plots size and were dispersed throughout the field. Other vines such as peppervine (*Ampleopsis arborea*) and grape (*Vitis* sp.) occurred sparingly within the fields.

Treatment Effects on Natural Invasion

Soil disturbance in the form of disking has been shown to have a significant effect on natural invasion rates (Allen and others 1998). In that study disking was shown to have a negative effect on the numbers of woody plants invading the plots. The effect of disking, however, appears to decrease through time(McCoy 1998). In the current study there were greater numbers of some species, especially the elms, on plots that had received little or no disking (SD or NT), but the effect was not significant when this study was sampled, at the end of the 6th growing season. None of the other silvicultural treatments examined in this study affected the rates of natural invasion by woody species. However, specific treatments that were positive for success of oaks were generally negative for the success of natural invaders.

Table 1—Mean number of stems/ha by size class and species. Size classes are: Class 1- > 30 to < 50, Class 2- > 50 to < 100, Class 3- > 100 to < 140, Class 4- > 140 to < 2.5 cm diameter at 140 cm height (DBH), Class 5- > 2.5 cm DBH. Frequency and stem densities are given for all size classes combined.

	CLASS					Frequency		Stems	
Species	1	2	3	4	5	Abs.	Rel.	Total	per / ha
Box Elder	0.0	0.3	0.0	0.3	0.0	2.0	2.4	2.0	0.6
Red Maple	0.3	2.7	0.9	0.0	0.0	10.0	11.9	13.0	3.9
Baccharis	0.0	0.0	0.0	3.6	0.0	6.0	7.1	12.0	3.6
Water Hickory	0.0	0.0	2.4	0.3	0.9	6.0	7.1	12.0	3.6
Sugarberry	3.6	51.2	33.9	20.5	0.3	73.0	86.9	368.0	109.5
Swamp Dogwood	0.0	0.3	0.0	0.0	0.0	1.0	1.2	1.0	0.3
Hawthorn	1.5	3.9	0.6	0.6	0.0	14.0	16.7	22.0	6.5
Persimmon	0.0	1.8	1.8	5.1	0.3	10.0	11.9	30.0	8.9
Ash	0.0	8.6	30.7	89.3	3.9	52.0	61.9	445.0	132.4
Honey-locust	0.0	1.5	2.1	7.7	2.4	25.0	29.8	46.0	13.7
Deciduous holly	2.4	3.3	2.7	3.9	0.0	30.0	35.7	41.0	12.2
Sweetgum	2.4	2.4	0.9	0.3	0.0	19.0	22.6	20.0	5.9
Swamp cottonwood	0.0	0.0	0.0	5.3	0.6	6.0	7.1	6.0	1.8
Wild cherry	0.0	0.0	0.0	0.0	0.3	1.0	1.2	1.0	0.3
Black willow	0.0	0.0	0.0	8.9	2.1	7.0	8.3	22.0	6.5
Elms	64.0	126.0	27.8	4.8	0.9	76.0	90.5	779.0	231.8
Total invaders	74.2	202.0	103.8	149.0	11.6	84.0	100.0	1821.0	541.9
Oaks	99.0	310.0	186.0	182.0	3.0	84.0	100.0	2626.0	781.5

Soils and elevation can also effect the establishment of tree species in old fields. In this study, greater numbers of sugarberry was found on the Tensas soil type along the natural levee of the Tensas River($p = 0.0458$).

Distance From Forest Edge / Seed Source

Distance from the nearby forest edge has been shown to have a significant effect on invasion rates (Allen and others 1998). A comprehensive analysis of the effects of distance on invasion rates is not possible in this study as no plots were closer than 129 m from the nearest forest edge and the subplot furthest from the forest edge was at a distance of 640 meters. We did, however, observe that the number of all invading species declined with increasing distance from the forest. Distances by quartiles (25, 50, and 25 percent of the individuals) showed 1038.8 individuals per ha (415.2/ac) between 129 - 259m, 635.1/ha (254.0/ac) between 260 - 406 m, and 301.3/ha (120.5/ac) at greater than 406 m. The numbers of subplots at each of the three distance regimes above were 45, 148, and 143.

General patterns of dispersal with distance, however, indicate differences for light versus heavy seeded species. Most (55.2 percent) light seeded species such as elms, ash, sweetgum, red maple, box elder, swamp cottonwood, and black willow occurred within 259 meters of the edge. Heavy seeded species seemed to follow one of two patterns. Species with the largest seeds, those usually transported by mammals, were typically found near the forest edge. This included species such as honeylocust and persimmon. Several species such as sugarberry, deciduous holly and hawthorns, usually transported by birds, were often found at greater average distances from the forest edge. Dispersal distances to be expected for any seed depends as much on the potential animals feeding on the seeds as on the seeds themselves (Johnson and others, 1985). However, soil type and therefore herbaceous communities associated with these soils differ with distance from the existing forest edge and could affect animal and bird use and seedling establishment rates.

Height classes and dbh

Overall, 51 percent of the saplings were less than 100 centimeters in height (table 1). The size class with the greatest number of saplings was 50-100 cm with 37.3 percent of all natural invaders. At the end of six growing seasons half the saplings were still at or below the average height of existing herbaceous vegetation and difficult to see at a casual glance. This makes the evaluation of afforestation success hard to measure and susceptible to seedling count errors. Even with a thorough search of the study subplots it is possible that some existing saplings were not observed or counted.

The short height of so many stems may be partially related to local browsing by deer and other herbivores. Many

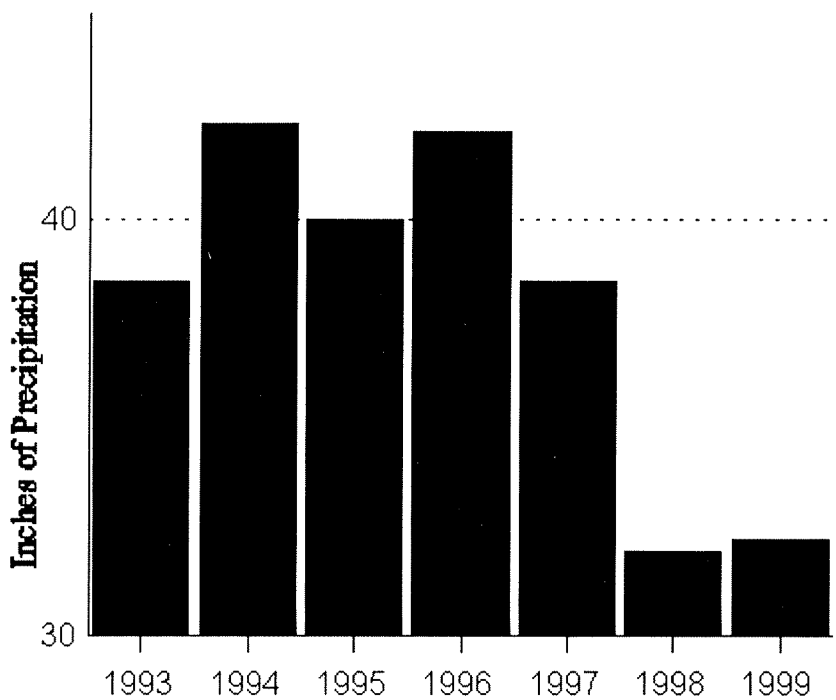


Figure 2—Inches of precipitation for the region of Tensas River NWR.

saplings, especially the elms and sugarberry, had obviously been damaged by browsing. The lower than average levels of precipitation for the years 1998 and 1999 may also have affected the growth of many saplings (figure 2).

Only 541 saplings (29.7 percent) were in excess of 140 cm tall, and only 2.1 percent of the trees had a measurable diameter (greater than 2.5 centimeters DBH). The average DBH of these taller saplings was 3.9 cm. Black willow had the largest mean DBH, 4.8 cm followed by honeylocust at 4.3 cm. The only other species with substantial numbers of stems greater than 2.5 cm DBH was ash, with an average of 3.3 cm. These three, fast-growing species represent 72.4 percent of all stems greater than 2.5 cm DBH. The honeylocust sapling's size may have been aided by reduced browsing associated with the large thorns all along the stem and branches. Honeylocust is intolerant of shade (Burns 1990) which may help explain the lack of shorter individuals of this species.

The distribution of saplings among the five height classes was highly variable among species (table 1). Sugarberry stems were distributed among all size classes, but perhaps under represented in the smallest size class. This may have been due to browsing. The distribution of ash stems was skewed toward the taller size classes. The low numbers of ash stems in the shorter size classes may not be related to browsing as very few ash stems showed any signs of herbivory. Of the 20 sweetgums counted in the plots these were mostly limited to the smaller size classes, but, again this did not seem related to browsing. Elms dominated the smaller size classes with few large stems. Browsing was evident on most elm stems and was probably a large factor in the observed greater numbers of stems less than 1m in height for this species.

CONCLUSIONS

Silvicultural planting treatments had little effect on the natural invasion of woody species onto these fields. Although some species, especially the elms, may be more numerous on plots with least disturbance (no till or strip disking) the effects were not significant at the 0.05 confidence level. The main factor affecting natural invasion rates was distance from the nearest forest edge. The effect of distance varied with species, seed size and disseminating agent (wind, birds, or other animals). Although the majority (75 percent) of most species with wind dispersed seeds were found within 392 m of the forest edge, some species with bird dispersed seeds were found in the most distant subplots, 640 m from the forest edge.

The effects of browsing on natural invasion and survival rates are not well understood. While many species, such as honeylocust, sweetgum, black willow and persimmon, appear not to have any browsing damage, other species, such as sugarberry, elms and the planted oaks, were heavily browsed. Browsing is probably having an effect on the successful establishment of many seedlings, but it appears that the species most heavily browsed are the ones invading in the greatest numbers. This level of browsing may not have an overall detrimental effect on the developing woody plant community as it may be promoting a more even species composition.

Height of the herbaceous plant community must be explicitly considered when assessing the success of a reforestation effort. In this study and in Allen and others (1998) the herbaceous vegetation was about 1 - 1.2 meters in height. At least half the saplings were below this height making them difficult to observe without a concerted effort. Persons conducting an evaluation before five to six years post planting may have difficulty finding all saplings within the sample area.

Interactions of the different effects such as distance and direction from existing forest edges, soil types, and disturbance makes analysis of this data complex. Unknown effects that further complicate the analysis includes browsing, existing forest edge species composition, and local climatic effects. However, an understanding of natural invasions onto former agricultural fields is being refined as more studies are completed.

REFERENCES

Allen, James A.; John W. McCoy; Bobby D. Keeland. 1998. Natural establishment of woody species on abandoned agricultural fields in the Lower Mississippi Valley: First- and second-year results. In: Waldrop, T.A., ed. Proceedings of the Ninth Biennial Southern Silvicultural Research Conference; 1997 February 25-27; Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture. Forest Service, Southern Research Station: 263-268.

Burns, Russell M.; Barbara H. Honkala, tech. Coords. 1990. Silvics of North America: 2. Hardwoods. Agric. Hand. 654. Washington, D.C: U.S. Department of Agriculture, Forest Service. Vol. 2, 877 p.

Daniel, R. S.; R. R. Fleet. 1999. Bird and small mammal communities of four similar-aged forest types of the Caddo lake area in east Texas. Texas Journal of Science 51(1): 65-80.

Hefner, J.M.I; J.D. Brown. 1985. Wetland trends in the southeastern United States. Wetlands 4: 1-11.

Johnson, Robert A.; Mary F. Willson; John N. Thompson; Robert I. Bertin. 1985. Nutritional values of wild fruits and consumption by migrant frugivorous birds. Ecology. 66(3): 819-827.

Kartesz, J.T. 1999. A Synonymized Checklist and Atlas with Biological Attributes for the Vascular Flora of the United States, Canada, and Greenland. First Edition. In: Kartesz, J.T., and C.A. Meacham. Synthesis of the North American Flora, Version 1.0. North Carolina Botanical Garden, Chapel Hill, NC.

King, S.L.; B.D. Keeland. 1999. Evaluation of reforestation in the Lower Mississippi River Alluvial Valley. Restoration Ecology. 7(4): 348-359.

McCoy, John W.; Bobby D. Keeland; James A. Allen. 1998. Natural establishment of woody species on previously farmed bottomland hardwood sites [Abstract]. In: 59th Annual Meeting of the Association of Southeastern Biologists; 1998 April 15-18; Northeast Louisiana University.

National Research Council. 1982. Impacts of emerging agricultural trends on fish and wildlife habitat. Washington, D.C: National Academy Press.

SAS Institute Inc. 1988. SAS/STAT User's Guide, Release 6.03 Edition, SAS Institute Inc.,Cary, NC: 1028 p.

COMPARING ALTERNATIVE SLASHING TECHNIQUES ON A MIXED HARDWOOD FOREST: 2-YEAR RESULTS

Donald G. Hodges, Richard M. Evans, and Wayne K. Clatterbuck[1]

Abstract—Regenerating commercially important species following the harvest of an existing mixed hardwood stand requires adequate advance regeneration of the desired species and control of competing vegetation. These objectives can be achieved by removing the noncommercial stems before or after harvesting. This study was designed to evaluate the efficacy of pre- and post harvest slashing alternatives and to assess cost differences between the alternatives. Four treatments (pre- and postharvest slashing, with and without herbicide stump treatment) and a control were selected. Each treatment was applied to a 120 feet x 120 feet plot within which measurements were taken on four 1/10-acre subplots. Each treatment was replicated six times within the harvest area, resulting in a total study area size of 9.9 acres. Preliminary results indicate that there was little difference between treatments in the total number of stems.

INTRODUCTION

A primary concern in harvesting mixed hardwood stands in the central hardwood region is ensuring adequate regeneration of the preferred commercially important species such as oak. Often competition from undesirable trees is too great for the commercially important species to overcome.

One means of enhancing oak regeneration is to control the competing species by slashing either prior to or immediately following harvest operations. Little information is available, however, to assess the relative effectiveness of the various slashing alternatives. Loftis (1978, 1985) evaluated the effectiveness and costs associated with preharvest treatments in southern Appalachian hardwoods. The results suggest that four years after clearcutting, preharvest treatments reduce the number of stems of undesirable species and increase the portion of desirable species in the stand. Ten years after clearcutting, stands that had received preharvest treatments were dominated by single stems of desirable species and stocking was excellent. Stands treated after the harvest operation contained a smaller percentage of desirable stems.

The research reported by Loftis used the postharvest treatments as a check on the effectiveness of the preharvest treatments. Moreover, only preharvest treatments involved herbicide applications. The purpose of our study was to evaluate how a stand developed after clearcutting when a variety of pre- and postharvest treatments were applied.

OBJECTIVES

The primary goal of the study was to evaluate alternative slashing techniques following harvest in a mixed hardwood forest. Specific objectives were to 1) assess the effect of pre- and post-harvest slashing and herbicide stump treatment of noncommercial stems on species composition flowing a silvicultural clearcut and 2) compare the costs associated with the pre- and post-harvest treatments.

METHODS

The site selected for the study is located on the Oak Ridge Forestry Experiment Station and consists of a 17-acre watershed. Elevations in the south-facing drainage range from 970 to 1100 feet above sea level. The harvested forest was comprised primarily of oaks (59 percent), yellow-poplar (*Liriodendron tulipifera*) (14 percent), miscellaneous hardwoods (10 percent), and pine (6 percent).

Five treatments were developed forcomparison in the study:

1 Preharvest Slash only
2 Preharvest Slash with Herbicide Stump Treatment
3 Postharvest Slash only
4 Postharvest Slash with Herbicide Stump Treatment
5 Control.

The five treatments were applied to 120 feet x 120 feet (0.331-acre) plots within the watershed. This plot size was large enough to distinquish individual treatments from surrounding treatments while allowing for several replications within the 17-acre study area. Each set of five treatments form a replication.

The 0.331-ac plots were located in the study site with the northwest corner serving as the starting point. From this point, the northwest corner of the initial plot was located approximately 25 feet to the southeast. Subsequent corners were located at 120-foot intervals by traveling on lines parallel and perpendicular to the initial line. A total of

[1]Associate Professor, Superintendent of Forestry Experiment Station, and Associate Professor, respectively; Department of Forestry, Wildlife and Fisheries; The University of Tennessee; P.O. Box 1071; Knoxville, TN 37901.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Species distribution by treatment, all stems, 1998

Species	Preharvest Slash	Preharvest Slash Herbicide	Postharvest Slash	Post-Harvest Slash & Herbicide	Control
Yellow-poplar	49.9	36.6	36.6	30.9	37.5
Red Maple	16.0	23.0	18.9	15.5	16.8
White Oak	2.1	2.8	2.9	2.6	3.3
Red Oaks	2.3	2.8	2.2	3.5	1.9
Blackgum	9.6	7.5	11.8	5.7	6.5

30 plots were identified in the study site, representing 6 replications.

Within each plot, four 1/1000-acre subplots were established for intensive sampling. These were located by running a line south 13 degrees east from the northern corner of each plot to establish the first subplot center. The remaining three center points were located by running a 60-foot line parallel to the boundary lines.

Plots were assigned to different replications by establishing groups of plots that were similar in terms of species composition, density, and location. A computer-generated design for incomplete blocks developed by Arnold Saxton of the Tennessee Agricultural Experiment Stations was used to assign treatments to plots.

The initial inventory was conducted on June 18-21, 1996. The inventory included all merchantable timber from 6 inches in DBH and above, with all sawtimber size hardwoods graded. All trees were measured within the subplots regardless of size during the last two weeks of September 1996. Data were recorded by 1 foot height classes up to 4 feet. Trees taller than 4 feet were classified into less than 1.5 inches DBH or larger than 1.5 inches DBH (exact DBH was recorded for this class).

Preharvest slashing was conducted on the designated plots during the first two weeks of October 1996. All stems greater than 1 foot in height were treated. On each plot, starting and ending times for treatment were recorded. The number of stems cut per plot was recorded as stems greater than or less than 1.5 inches DBH. Garlon 3A 50/50 with water and red dye was used on all noncommercial stumps in the plots designated as preharvest slashing and herbicide stump treatment. Start and stop times were recorded for herbicide application as well as the amount of herbicide used and the number of stumps treated.

The timber harvest operation was conducted from February 5 to April 30, 1997. Approximately 118.9 MBF (Doyle) of hardwood sawtimber, 7.0 MBF of pine sawtimber, 29.2 cords of hardwood pulpwood, and 9.0 cords of pine pulpwood were removed.

Postharvest slashing was conducted on the designated plots on August 1, 1997, with start and stop times recorded as well as the number of stems cut per plot. The stems were categorized by DBH (less than or greater than 1.5 inches). Postharvest slashing and herbicide treatment plots were treated on August 15, 1997. The stump treatment consisted of Garlon 4 50/50 with oil and red dye. As with the preharvest treatments, start and stop times were recorded for herbicide application as well as the amount of herbicide used and the number of stumps treated.

All subplots were remeasured two years after harvest (summer 1998) to assess the effectiveness of the various treatments. Similar data were collected as described above for initial measurements of the treatment plots: species and number of stems by height class up to 4 feet and by diameter class of stems greater than 4 feet.

Table 2—Species distribution by treatment, stems > 4 feet, 1998[a]

Species	Preharvest Slash	Preharvest Slash & Herbicide	Postharvest Slash	Postharvest Slash & Herbicide	Control
Yellow-poplar	22.8a	20.8ab	12.6c	15.8c	14.3c
Red Maple	13.1a	23.0b	18.9a	15.5a	25.5a
White Oak	0.2ab	0.2ab	0.6bc	0.7c	0.1a

[a] Similar letters represent percentages that are not significantly different at a = 0.05.

Table 3—Average activity by treatment

Treatment	Cutting (# trees/acre)	Herbicide (# trees/acre)	Time (minutes)	Cost ($/acre)
Preharvest	948		129	$25.65
Preharvest/Herbicide	1383	607	310	$94.39
Postharvest	308		121	$19.69
Postharvest/Herbicide	426	387	216	$57.64

RESULTS AND DISCUSSION

The results of the two-year data suggest that the four treatments may vary in their effects on species composition, although statistical analysis reveals few significant results. Table 1 depicts the total number of stems by major species that were counted on the subplots. Few discernible differences were identified by this preliminary analysis. Yellow-poplar and red maple (*Acre rubrum*) were the predominant species for all treatments and the control plots. Oaks comprised less than 7 percent of the stems for all treatments. Plots with herbicide treatments (both pre- and postharvest) contained a larger component of oaks than the control or non-herbicide treatments.

Examining species composition differences among the larger stems (> 4 feet) revealed some statistically significant differences among treatments. Table 2 lists the percent of all stems counted for the species of primary interest by treatment type. Preharvest treatments resulted in a significantly larger portion of the stems being comprised of yellow-poplar saplings. Conversely, postharvest treatments contained a significantly larger percentage of large white oak saplings than the control or preharvest treatments.

The cost results reveal that the preharvest treatments were significantly more expensive than the post harvest treatments for both non-herbicide and herbicide alternatives (table 3). These results are similar to those reported by Loftis (1978) and can be explained by the level of activity required in each plot. The work crews treated more than 3 times as many stems in the preharvest plots than they recorded in the postharvest plots. The harvesting activity resulted in many of the stems in the postharvest plots being severed before treatment was applied. As a consequence, less work was required after harvest—which reduced the costs considerably. Loftis (1978) noted, however, that an equally effective alternative could have been employed that would have reduced the preharvest treatment costs substantially. In the Oak Ridge study, similar modifications in the treatments would reduce costs as well.

No conclusions can be drawn, however, regarding the cost-effectiveness of the alternatives. Although the preliminary results suggest that postharvest treatments have resulted in desirable species comprising a greater percentage of the larger stems than in the preharvest treatments, it is too early to conclude that this will continue throughout the life of the stand. Loftis (1985) reported that desirable stems in plots receiving postharvest treatments were beginning to be replaced by undesirable sprouts in many instances by year 10. If similar patterns emerge in the Oak Ridge stand, the cost-effectiveness of the alternatives could change significantly.

REFERENCES

Loftis, David L. 1978. Preharvest herbicide control of undesirable vegetation in southern Appalachian hardwoods. Southern Journal of Applied Forestry. 2: 51-54.

Loftis, David L. 1985. Preharvest herbicide treatment improves regeneration in southern Appalachian hardwoods. Southern Journal of Applied Forestry. 9: 177-180.

SEVENTEEN-YEAR GROWTH OF CHERRYBARK OAK AND LOBLOLLY PINE ON A PREVIOUSLY FARMED BOTTOMLAND SITE

Warren D. Devine, John C. Rennie, Allan E. Houston, Donald D. Tyler, and Vernon H. Reich[1]

Abstract—This study documents the effects of cultural treatments on 17-year growth of cherrybark oak (*Quercus pagoda* Raf.) and loblolly pine (*Pinus taeda* L.) planted on a previously farmed bottomland site in southwestern Tennessee. Yellow-poplar (*Liriodendron tulipifera* L.) was part of the original study, but was excluded due to very high mortality in early years. The experiment was a randomized, complete-block design located on a former soybean field prone to occasional flooding. Cultural treatments were third-year fertilization (nitrogen and phosphorus) as well as disking and mowing for weed control. Natural regeneration as a means of afforestation also was investigated. Survival after 17 years averaged 64 percent for cherrybark oak and 63 percent for loblolly pine. Mean total height was 34.0 feet for cherrybark oak and 55.0 feet for loblolly pine. The mean diameters at breast height (DBH) of cherrybark oak and loblolly pine were 4.1 and 10.2 inches, respectively. Survival, height, and DBH of both species were not significantly affected by fertilization, mowing, or disking, nor were there any significant interactions among the treatments. Natural regeneration resulted in dense stands (4,340 trees per acre) dominated by small-diameter sweetgum (*Liquidambar styraciflua* L.).

INTRODUCTION

A number of studies have investigated afforestation of abandoned agricultural wetlands in the Mississippi Valley, but few studies have provided long-term results of afforestation practices on these sites. A plantation in southwest Tennessee provided the opportunity to observe seventeen-year effects of cultural treatments on a highly desirable bottomland hardwood species and an adaptive pine likely to perform well on such sites.

Cost share programs such as the Conservation Reserve Program and the Wetland Reserve Program have encouraged afforestation of farmed wetlands. The cultural practices used on these sites to improve early growth and to insure dominance of tree seedlings have varied. Mowing or disking for weed control is not as common today as in the past, but it is still important to understand the residual effects of these establishment practices on bottomland plantations. The primary objective of this study was to determine the suitability of cherrybark oak and loblolly pine for planting on a previously farmed bottomland site, and to evaluate the effects of cultural treatments on their establishment and growth. The planted plots in this study also were compared to a naturally regenerated area on the same site.

METHODS

The study took place on the Ames Plantation in Fayette County, Tennessee, 50 miles east of Memphis (35° 07' N and 89° 19' W). The site was a former soybean field on a floodplain of the North Fork of the Wolf River. According to the USDA Natural Resources Conservation Service county soil map, soils are of the Waverly (Coarse-silty, mixed, acid, thermic Typic Fluvaquents) and Falaya series (Coarse-silty, mixed, active, acid, thermic Aeric Fluvaquents) (Flowers 1964). The Falaya series consists of somewhat poorly drained silty and sandy alluvium, and the Waverly series is a poorly drained silty alluvial soil. The study site had been in cultivation for more than 20 years prior to the establishment of hardwoods in 1981. Mean annual precipitation is 53 inches (Flowers 1964).

In spring of 1981, 1-0 seedlings were hand-planted among the previous year's soybean stubble at a 10- x 10-foot spacing. The study initially included 1,200 each of cherrybark oak, loblolly pine, and yellow-poplar seedlings. However, the yellow-poplar suffered very high mortality and was excluded from the study after the first 2 years.

The experiment was a randomized, complete-block design with a strip-plot treatment arrangement and four replications. Main plot treatments were arranged in a 2 x 3

[1]Graduate Research Assistant, Associate Professor,Department of Plant and Soil Sciences,The University of Tennessee Department of Plant and Soil Sciences,The University of Tennessee,P.O. Box 1071,Knoxville, TN 37901-107; Professor Emeritus,Department of Forestry, Wildlife, and Fisheries,The University of Tennessee; [2]Research Associate Professor,Ames Plantation,P.O. Box 389, Grand Junction, TN 38039; Professor,West Tennessee Experiment Station,605 Airways Boulevard,Jackson, TN 38301, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

factorial composed of fertilized and unfertilized plots of the 3 species. The fertilization treatment was 150 pounds per acre nitrogen (ammonium nitrate) and 35 pounds per acre phosphorus (triple super phosphate) applied at the beginning of the third growing season. Three treatments were tested on the sub-plot level: disking, mowing, and no weed control. One-way disking and mowing were repeated as needed (three to five times annually) until the end of the fifth growing season to control competing vegetation. The plantings were never thinned. A 1.2-acre section of the same soybean field was left to regenerate naturally.

In January 1998, 17 years after planting, total height of each surviving tree was measured with a Haga altimeter. Diameter at breast height (DBH) was measured with a caliper. In the naturally regenerated area, 10 circular, 0.01-acre plots were randomly placed. Height, DBH, and species were recorded for each stem on these plots greater than 4.5 feet in height. Equations developed by Matney and others (1985) and Baldwin and Feduccia (1987) were used to estimate total bole volumes of individual trees outside bark. Stand volume estimates ($feet^3$ per acre) were calculated based on estimated tree volumes, survival rates, and planting density. Survival and growth data were analyzed by Analysis of Variance (ANOVA) using Proc Mixed in SAS (SAS Institute Inc 1997). Survival data were transformed with the arcsine-square root transformation to meet the normality and homoscedasticity requirements of ANOVA. Post-ANOVA mean separations were made with single degree of freedom contrasts (alpha = 0.05).

RESULTS AND DISCUSSION

Survival for cherrybark oak averaged 89 percent after 1 year, 77 percent after 2 years, and 64 percent after 17 years. Loblolly pine survival averaged 80 percent, 74 percent, and 63 percent after 1, 2, and 17 years, respectively. Fertilization and weed control treatments did not significantly affect survival at any age for either species (table 1).

Table 1—Survival after 1, 2, and 17 years for planted cherrybark oak and loblolly pine under six different treatment combinations[a]

Species/ Fertilization/ Weed Control	Age 1	Age 2	Age 17
		Percent	
Cherrybark oak			
Unfertilized/ None	88	73	62
Unfertilized/ None	88	78	72
Unfertilized/ Mowed	88	70	66
Fertilized/ None	91	81	66
Fertilized/ Disked	94	80	60
Fertilized/ Mowed	89	79	57
Lobolly Pine			
Unfertilized/ None	73	68	45
Unfertilized/ None	86	74	72
Unfertilized/ Mowed	80	80	66
Fertilized/ None	79	73	54
Fertilized/ Disked	81	77	66
Fertilized/ Mowed	83	76	76

[a] There were no significant differences among treatment combinations for either species at alpha=0.05.

Seventeen-year height, DBH, basal area, and stand volume for both species were not significantly affected by fertilization or weed control treatment, nor were there any significant treatment interactions. Although there were numerical differences among some of the treatment means, the variability of cherrybark oak height and diameter among blocks (replications) prevented any statistically significant differences. Loblolly pine had consistent height and diameter among both blocks and treatments, but survival rates varied widely among blocks.

Cherrybark oak had a mean height of 34.0 feet and a mean DBH of 4.1 inches after 17 years (tables 2 and 3). Because cherrybark oak it best suited to well drained soils (Krinard 1990), the poor drainage on parts of the study site may have hindered growth and root development. It is likely that soils in this study were more variable than indicated by the county soil map (Flowers 1964). A neighboring bottomland study in which soils were evaluated showed wide variations in soil properties including drainage over distances of less than 100 feet (Devine and others 2000). Even minor variations in soils can have major impacts on the success of planted hardwoods (Kormanik and others 1999). Due to the slow growth rate of the cherrybark oak, the 17-year-old plantation still had not formed a canopy sufficient to shade out competition. Several areas were heavily infested with Japanese honeysuckle (*Lonicera japonica Thunberg*) and other herbaceous and woody weed species. There was a visible reduction in woody competition on plots which had been disked or mowed, but this did not translate into a significant increase in growth for the plantation trees.

Cherrybark oak averaged 32.8 $feet^2$ per acre basal acre after 17 years of growth (table 4). The potential merchantability of this stand will depend on whether growth rates increase in the near future. On some of the plots, enough woody competition had already become established to make the planted trees a relatively minor component of the stand. Clatterbuck and Hodges (1988) noted that cherrybark oak reached its maximum growth rate later than sweetgum and eventually exceeded it in height. It is possible that this could occur in the present study because sweetgum is the predominant co-occurring species.

Table 2—Height after 17 years for planted cherrybark oak and loblolly pine under six treatment combinations[a]

Fertilization/ Weed control	Cherrybark Oak	Loblolly Pine
	----- Feet -----	
Unfertilized/None	30.4	53.7
Unfertilized/Disked	37.1	56.1
Unfertilized/Mowed	33.3	56.5
Fertilized/None	32.8	52.3
Fertilized/Disked	34.6	56.0
Fertilized/Mowed	35.8	54.3

[a] There were no significant differences among treatment combinations for either species at alpha=0.05.

By year 17, loblolly pine had reached a mean DBH of 10.2 inches and a mean total height of 55.0 feet. Diameter and height growth was quite consistent among all treatments, and the plots had long since formed a closed canopy. At age 17 there was virtually no weed competition present in the pine plantings. Basal area averaged 160.9 ft^2 per acre for all treatments. Variations in basal area and stand volume of loblolly pine in tables 4 and 5 are a reflection of variation in survival among treatments and not of variation in growth. However, because survival rates varied widely among replications, there were no statistically significant differences in basal area or stand volume due to treatments. Hopper and others (1993) found that weed control, but not fertilization, increased growth and survival at age 4 of loblolly pine, sweetgum, and green ash (*Fraxinus pennsylvanica* Marsh.) planted on a West Tennessee bottomland site. Hunt and Cleveland (1978) also found that disking, but not fertilization at planting, increased height growth of loblolly pine through age 5. If differences in growth of loblolly pine due to weed control or fertilization were present early in the current study, they have since disappeared.

Table 3—DBH after 17 years for planted cherrybark oak and loblolly pine under six treatment combinations[a]

Fertilization/ Weed control	Cherrybark oak	Loblolly Pine
	------ Inches ------	
Unfertilized/None	3.5	10.0
Unfertilized/Disked	4.7	10.1
Unfertilized/Mowed	4.3	10.3
Fertilized/None	3.7	10.3
Fertilized/Disked	4.4	10.3
Fertilized/Mowed	4.2	09.9

[a] There were no significant differences among treatment combinations for either species at alpha=0.05.

Table 4—Stand basal area after 17 years for planted cherrybark oak and loblolly pine under six treatment combinations[a]

Fertilization/ Weed control	Cherrybark Oak	Loblolly Pine
	---- Feet^2 per acre ----	
Unfertilized/None	25.0	110.2
Unfertilized/Disked	42.8	179.7
Unfertilized/Mowed	41.7	171.2
Fertilized/None	23.1	142.3
Fertilized/Disked	32.5	170.7
Fertilized/Mowed	31.4	183.2

[a] There were no significant differences among treatment combinations for either species at alpha=0.05.

On disked plots of both species, 6- to 12-inch deep depressions were present between the tree rows. These depressions were accompanied by small ridges in line with the rows. Both features were likely caused by compaction and heaving of soil that resulted from disking. During wet periods, water ponded in the majority of these depressions, most notably those in poorly-drained areas. These depressions were still present 12 years after the plots had last been disked.

Natural regeneration resulted in dense stands (4,340 trees/acre) of sweetgum (74 percent of stems), boxelder (*Acer negundo* L.) (12 percent), red maple (*Acer rubrum* L.) (11 percent), and other hardwoods. Over 99 percent of the stems in this stand were less than 5 inches in DBH, and 46 percent of the stems were less than 1 inch in DBH. Species composition of this stand was heavily influenced by the adjacent, mature forest stands. The naturally-regenerated stand clearly had low potential for merchantability at age 17.

Table 5—Stand volume (total bole) after 17 years for planted cherrybark oak and loblolly pine under six treatment combinations[a]

Fertilization/ Weed control	Cherrybark Oak	Loblolly Pine
	-----Feet^3 per acre-----	
Unfertilized/None	469	2,953
Unfertilized/Disked	895	4,965
Unfertilized/Mowed	744	4,788
Fertilized/None	553	3,455
Fertilized/Disked	629	4,726
Fertilized/Mowed	630	5,008

[a] There were no significant differences among treatment combinations for either species at alpha=0.05.

CONCLUSIONS

Loblolly pine planted on a bottomland soybean field with no site preparation established a well-stocked stand by age 17. Cherrybark oak plots showed inconsistent growth, perhaps due to variations in soils. A single application of N and P fertilizers at year 3 did not increase growth of cherrybark oak or loblolly pine, nor did mowing or disking for weed control. Since disking resulted in depressions between tree rows still present 12 years after the site was last disked, its usefulness as a method of weed control on flood-prone or poorly-drained sites is questionable. The depressions increase the amount of time that water ponds on the soil which can be detrimental to the growth and survival of planted tree species not adapted to periods of extended flooding. Composition of natural regeneration on the former soybean field depended on neighboring stands and did not produce merchantable trees after 17 years.

ACKNOWLEDGMENTS

The authors would like to thank the Hobart Ames Foundation, whose direct support made this research possible. We would also like to thank Dr. Ed Buckner, originator of this study.

REFERENCES

Baldwin, V.C., Jr.; Feduccia, D.P. 1987. Loblolly pine growth and yield prediction for managed west gulf plantations. Res. Pap. SO-236. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 27 p.

Clatterbuck, W.K.; Hodges, J.D. 1988. Development of cherrybark oak and sweetgum in mixed, even-aged bottomland stands in central Mississippi, U.S.A. Canadian Journal of Forest Research. 18: 12-18.

Devine, W.D.; Houston, A.E.; Tyler, D.D. 2000. Growth of three hardwood species through 18 years on a former agricultural bottomland. Southern Journal of Applied Forestry. 24(3): 159-165.

Flowers, R.L. 1964. Soil survey-Fayette County Tennessee. Washington, DC: U.S. Department of Agriculture Soil Conservation Service. 71 p.

Hopper, G.M.; Buckner, E.R.; Mullins, J.A. 1993. Effects of weed control and fertilization on plantation establishment and growth of green ash, sweet gum, and loblolly pine: four year results. In: Brissette, J.C., ed. Proceedings of the seventh biennial southern silvicultural research conference; 1992 November 17-19; Mobile, AL. Gen. Tech. Rep. SO-93. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 357-360.

Hunt, R.; Cleveland, G. 1978. Cultural treatments affect growth, volume, and survival of sweetgum, sycamore, and loblolly pine. Southern Journal of Applied Forestry. 2(2): 55-59.

Kormanik, P.P.; Kormanik, T.L.; Sung S.S.; Zarnoch, S.J.; Possee, C. 1999. Artificial Regeneration of Multiple Hardwood Species to Develop Specific Forest Communities. In: Haywood, J.D., ed. Proceedings on the tenth biennial southern silvicultural research conference; 1999 February 16-18; Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S, Department of Agriculture, Forest Service, Southern Research Station: 132-136.

Krinard, R.M. 1990. Cherrybark Oak. In: Burns, R.M.; Honkala, B.H., tech. cords. Silvics of North America. Agric. Handb. 654. Washington DC: U.S. Department of Agriculture, Forest Service: 644-649. Vol. 2.

Matney, T.G.; Hodges, J.D.; Sullivan, A.D. [and others] 1985.Tree profile and volume ratio equations for sweetgum and cherrybark oak trees. Southern Journal of Applied Forestry. 9: 222-227.

SAS Institute Inc. 1997. SAS/STAT Software: Changes and Enhancements through release 6:12, Cary, NC: SAS Institute Inc. 1,176 p.

Biometrics

Moderators:

JIM M. GULDIN
USDA Forest Service

and

RALPH AMATEIS
Virginia Polytechnic Institute

EMPIRICALLY DERIVED OPTIMAL GROWTH EQUATIONS FOR HARDWOODS AND SOFTWOODS IN ARKANSAS

Don C. Bragg[1]

Abstract—Accurate growth projections are critical to reliable forest models, and ecologically based simulators can improve silvicultural predictions because of their sensitivity to change and their capacity to produce long-term forecasts. Potential relative increment (PRI) optimal diameter growth equations for loblolly pine, shortleaf pine, sweetgum, and white oak were fit to data from the Arkansas portion of the Eastwide Forest Inventory Data Base (EFIDB). Large sample sizes are necessary for successful application of the PRI methodology, and in aggregate almost 29,000 trees were used to develop these models. In the final model versions, only a handful (< 30 per species) of the fastest growing trees given their species, size, and growing conditions were retained from the Arkansas EFIDB. Shortleaf pine, sweetgum, and white oak all generated skewed model curves, while loblolly pine produced a monotonically declining curve. Comparison of these optimal increment models across tree size indicated that loblolly pine had higher potential than the other species until ~ 10 cm in diameter at breast height (d.b.h.), after which sweetgum and white oak overtook it at intermediate sizes. However, loblolly pine optimal performance decreased at a lesser rate than any of the other species, so that by 60 cm d.b.h. it once again had the greatest potential. The other taxa outperformed shortleaf pine throughout most of the diameter range considered, while sweetgum proved intermediate between shortleaf and white oak. These optimal diameter functions are a valuable first step in the development of forest simulators.

INTRODUCTION

Foresters have increasingly used models to predict long-term stand dynamics. Empirically based growth and yield models, e.g., Lynch and others (1999), Wykoff and others (1982), are popular because they are relatively easy to parameterize. However, the rigid nature of these designs, their finite analysis options, and their lack of ecological mechanism have limited their applicability beyond short-term growth-and-yield prediction. Ecological process models are becoming more widespread, e.g., Botkin and others (1972), Bragg (1999), Pacala and others (1993), in part because of their greater complexity and flexibility. However, these models often lack an empirical foundation and sometimes rely upon questionable assumptions. Blending the positive features of empirical and ecological models should improve the reliability of long-term forecasts of forest dynamics.

Most forest simulators include some kind of individual tree growth model. A fundamental goal of this increment model is to predict realized growth accurately, and there are at least two different ways to approach this problem. Most empirical models use a fitted statistical response where increment is either added or subtracted from a standard level, depending on how favorable conditions are for growth, e.g., Wykoff and others (1982). While commonly applied, this design limits the growth function to a specified set of modifiers, thus restricting its adaptability. The other primary approach employs a potential increment function that is rescaled downward based on departures from optimal growth conditions, e.g., Botkin and others (1972), Bragg (2001). Thus, one predicts realized growth from its departure from optimal growth using appropriate modifier function(s). In principle, this strategy has greater flexibility for ecological modeling because environmental response functions can be more sophisticated and mechanistic. However, one of the biggest challenges to optimal growth modeling lies in the development of an acceptable response curve.

Researchers have developed and evaluated numerous designs of potential growth equations (Botkin and others 1972, Moore 1989, Pacala and others 1993, Zeide 1993). Most recently, Bragg (2001) developed the Potential Relative Increment (PRI) methodology to fit inventory data to an ecologically robust function, thus linking desirable theoretical and statistical properties. This paper presents optimal PRI increment models for loblolly pine (Pinus taeda L.), shortleaf pine (P. echinata Mill.), sweetgum (Liquidambar styraciflua L.), and white oak (Quercus alba L.) in Arkansas using data from the Eastwide Forest Inventory Data Base (EFIDB) (Hansen and others 1992).

METHODS

The details of the PRI method are beyond the scope of this paper (see Bragg 2001). Briefly, all records of the species of interest with positive growth were selected for processing. After identifying this initial group, those individuals growing at the greatest rate for each 2-cm diameter at breast height (d.b.h.) class (one tree per size class) were segregated into a maximal actual increment

[1]Research Forester, USDA Forest Service Southern Research Station, P.O. Box 3516 UAM, Monticello, AR 71656 USA

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Statistics on the four species extracted from the Arkansas portion of the Eastwide Forest Inventory Data Base

Species	Original sample size	Minimum d.b.h.	Maximum d.b.h.	Standard d.b.h. deviation
		- - - - - - - - - - - *Centimeters*	- - - - - - - - - -	
Loblolly pine	11,340	2.8	88.6	13.52
Shortleaf pine	7,587	2.8	70.1	10.57
Sweetgum	3,906	2.8	111.3	14.13
White oak	6,089	2.8	100.8	13.70

Table 2—Final model regression coefficients (b_1, b_2, and b_3), goodness-of-fit, and final sample sizes

Species	b_1	b_2	b_3	R^2	Loss[a]	Final n[b]
Loblolly pine	2.708480	-1.033813	0.993497	0.9975	0.00284	29
Shortleaf pine	1.171747	-.623995	.962244	.9953	.00278	25
Sweetgum	.439226	-.053773	.944559	.9942	.00109	16
White oak	.273683	.086414	.955673	.9960	.00028	12

[a] Loss = Σ(observed - predicted)^2.

[b] Final number of points used to fit the optimal potential relative increment curves and generate the R^2 values in this table.

pool. From these, a best subset was identified to fit the PRI growth function:

$$PRI = b_1 D_{MAX}^{b_2} \, b_3^{D_{MAX}} \qquad (1)$$

where

D_{MAX} = the d.b.h. of the maximally performing individual (by size class) and
b_1 to b_3 = species-specific nonlinear ordinary least squares regression coefficients.
Optimal increment is the product of PRI and current d.b.h., while realized increment can be estimated by multiplying optimal increment with limiting environmental scalar(s) (Bragg 2001). In this final step, factors such as competition and site quality come into play.

The spatially extensive sample found in the EFIDB covers most of the possible variation in the environment. However, the odds of finding a Forest Inventory and Analysis plot with the perfect combination of site quality, stand density, and genetics to produce a truly optimal growth environment are negligible. Therefore, the PRI methodology is a conservative representation of potential diameter growth (Bragg 2001). The inference that optimal conditions can be approximated from inventory data requires a large sample of trees of the desired species from an extensive area. To ensure adequate representation, almost 29,000 individuals from the taxa of interest were selected from the Arkansas portion of the EFIDB (11,340 loblolly pines, 7,587 shortleaf pines, 3,906 sweetgums, and 6,089 white oaks) (table 1).

Only a small fraction (< 30 per species) of the records were retained for the final models (table 1). Loblolly pine provides an example of the iterative fitting process. Originally, over 11,000 records were considered usable, covering most of the range of possible size and increment with little apparent measurement error (fig. 1A). The exception is an outlier identified by the arrow in figures 1A and 1B. This tree apparently grew from 61.0 cm d.b.h. to 90.2 cm d.b.h. in 7.2 years (an average of 4.2 cm annually), a highly dubious rate given the size of the tree. Of the initial multitude of records, 42 loblolly were chosen, one for each respective diameter class (fig. 1B). Since the objective of the methodology was to identify an optimal growth curve, individuals within the d.b.h. class structure that did not maximize this function were removed (including the outlier). Thus, a final subset of 29 loblolly pines was retained for curve fitting (fig. 1C). This process was repeated for the other species until a suite of models was developed.

RESULTS AND DISCUSSION

Figure 2A illustrates that optimal increment performance is a distinct function of species and size. Translated into the more interpretable measure of potential annual d.b.h.

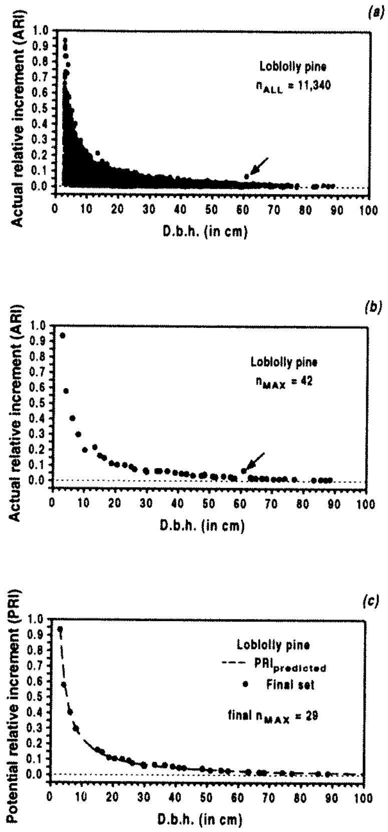


Figure 1—Graphical demonstration of the potential relative increment (PRI) methodology for loblolly pine in Arkansas. After the initial sample (n_{ALL}) of 11,340 loblolly pines was chosen (A), only the points (n_{MAX}) representing the highest growth performance within each 2-cm d.b.h. class remained after an initial filtering (B). Further discrimination resulted in a subset (final n_{MAX} = 29) used to develop the PRI model (C). Note the arrows in (A) and (B) that identify the outlier removed before final model fitting.

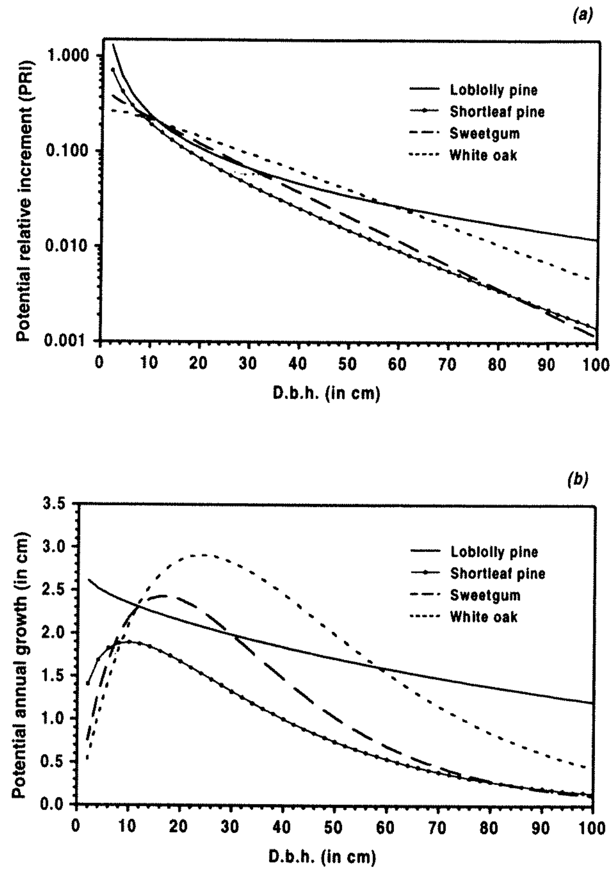


Figure 2—Annual potential relative increment (PRI) (A) and potential annual growth (B) for loblolly pine, shortleaf pine, sweetgum, and white oak. The differences in the PRI curves yield dramatic differences in optimal growth performance between species.

growth (fig. 2B), differences in performance become even more marked. Shortleaf pine, sweetgum, and white oak all produced skewed model curves with different local maxima and trajectories, while loblolly pine yielded a monotonically declining curve with a maximum at the smallest d.b.h. class. Thus, for the smaller diameters (< 12 cm), loblolly pine had the potential to outgrow any of the other species in this sample, especially shortleaf pine and sweetgum. However, between 12 and 30 cm d.b.h., both sweetgum and white oak were predicted to have higher potential performance than loblolly pine, with white oak continuing this trend to 60 cm. From 60 centimeters on, loblolly regained its dominance over the other species.

Shortleaf pine failed to approach the maximal performance of sweetgum and white oak until very large diameters, and never matched loblolly's potential. Sweetgum performed at an intermediate level until larger diameters were reached, upon which its optimal performance decreased noticeably. Note that these results are for predictions of potential increment, not those realized in the field: actual diameter growth will be a function of factors such as

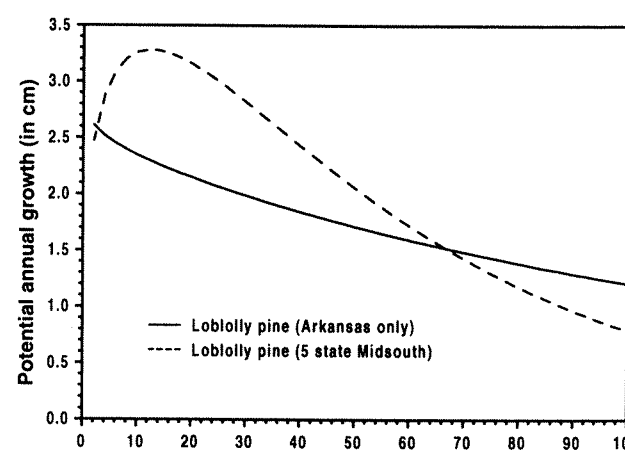


Figure 3—Comparison of the Arkansas potential relative increment model of loblolly pine (solid line) and the Midsouth model (Unpublished manuscript. D.C. Bragg, Research Forester, USFS Southern Research Station, P.O. Box 3516 UAM, Monticello, AR 71656) that included Arkansas (dashed line). The Midsouth model benefited from supplemented and extended size classes, thus resulting in a noticeably different prediction of potential tree performance.

localized edaphic, climatic, and competitive conditions, photosynthetic surface area, tree moisture status, genetic predisposition, or the presence of pathogens.

From these data, it appears loblolly pine has the potential to add the greatest diameter increment (2.6 cm annually) at the smallest size, while shortleaf pine peaks (~ 1.9 cm annually) at approximately 8 to 10 cm d.b.h., sweetgum reaches a maximum (~2.4 cm annually) at 15 to 18 cm d.b.h., and white oak crests (~2.9 cm annually) at approximately 25 cm d.b.h.. These results differ from a more extensive set of PRI curves fit to an inventory pool for the Midsouth (Arkansas, Louisiana, Missouri, Oklahoma, and Texas).[2] Using loblolly pine as an example, noticeable differences in potential increment are apparent at both small and large diameters (fig. 3).

Under the Midsouth model, a skewed model form replaces the monotonically declining model of the Arkansas-only data, with a new, higher maximal annual growth peak of > 3.2 cm now found at ~ 15 cm d.b.h. Optimal growth potential remains higher until loblolly pine reaches > 65 cm d.b.h., after which it drops below the Arkansas model. The data used for the Midsouth model changed the curve shape dramatically by adding points at small diameters that produced more optimistic optimal performance while simultaneously contributing new observations in the larger diameter classes. Pooling can increase confidence in results by supplementing and/or extending the range of sample data. In some cases, though, pooling may overestimate local growth potential if environmental and genetic conditions are significantly different from the more limited study area. Because of similarities in the environmental and loblolly genetic conditions in the Midsouth, the increase in potential optimal performance noted in figure 3 should not cause major problems when applied in Arkansas.

CONCLUSIONS

Optimal tree diameter growth performance is a function of both species and size. In this Arkansas sample, loblolly pine and white oak outperformed sweetgum and shortleaf pine. However, all species considered in this paper can potentially add 2 to 3 cm of diameter annually. The ability to differentiate species performance based on standardized growth functions should help the forest research community, especially if the inventory information is widely available.

Large public databases like the EFIDB can assist the development of silvicultural and mensurational applications. Their considerable spatial extent, rigorous sampling design, and broad range of species and size classes also favor their use in other fields, especially ecological modeling. The development of empirically derived optimal growth models provides the basis for forest simulators grounded in both theory and reality.

ACKNOWLEDGMENTS

I thank the following people and institutions for their support of this work: Dave Roberts (Utah State University), Tom Crow (USDA Forest Service, North Central Research Station), and Jim Guldin (USDA Forest Service, Southern Research Station). Reviews from the following improved the quality of this manuscript: Jim Guldin, Boris Zeide (University of Arkansas at Monticello), Bernie Parresol (USDA Forest Service, Southern Research Station), and David Larsen (University of Missouri at Columbia).

LITERATURE CITED

Botkin, D.B.; Janak, J.F.; Wallis, J.R. 1972. Some ecological consequences of a computer model of forest growth. Journal of Ecology. 60: 849–872.

Bragg, D.C. 1999. Multi-scalar spatial modeling of northern forest dynamics: foundations, theories, and applications. Logan, UT: Utah State University. 532 p. Ph.D. dissertation.

Bragg, D.C. 2001. Potential relative increment (PRI): a new method to empirically derive optimal tree diameter growth. Ecological Modelling. 137: 77–92.

Hansen, M.H.; Frieswyk, T.; Glover, J.F.; Kelly, J.F. 1992. The Eastwide Forest Inventory Data Base: users manual. Gen. Tech. Rep. NC–151. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 48 p.

Lynch, T.B.; Hitch, K.L.; Huebschmann, M.M.; Murphy, P.A. 1999. An individual-tree growth and yield prediction system for even-aged natural shortleaf pine forests. Southern Journal of Applied Forestry. 23: 203–211.

Moore, A.D. 1989. On the maximum growth equation used in forest gap simulation models. Ecological Modelling. 45: 63–67.

Pacala, S.W.; Canham, C.D.; Silander, J.A. 1993. Forest models defined by field measurements: I. The design of a northeastern forest simulator. Canadian Journal of Forest Research. 23: 1980–1988.

Wykoff, W.R.; Crookston, N.L.; Stage, A.R. 1982. User's guide to the stand prognosis model. Gen. Tech. Rep. INT–133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 112 p.

Zeide, B. 1993. Analysis of growth equations. Forest Science. 39: 594–616.

[2] Bragg, D.C. Unpublished manuscript.

A METHOD FOR ASSESSING ECONOMIC THRESHOLDS OF HARDWOOD COMPETITION

Steven A. Knowe[1]

Abstract—A procedure was developed for computing economic thresholds for hardwood competition in pine plantations. The economic threshold represents the break-even level of competition above which hardwood control is a financially attractive treatment. Sensitivity analyses were conducted to examine the relative importance of biological and economic factors in determining economic thresholds. Growth models were used to determine the level of hardwood basal area (HBA) at which the cost of hardwood control equals the reduction in net present value of the stand due to competition. A basal area prediction model was fit with absolute HBA, rather than percent HBA, and then used to simulate the effects of hardwood competition in loblolly pine plantations. Generalized yield response models at age 25 were developed by site index and HBA, and used to compute HBA when the net present value of the pine response was zero. A hardwood basal area growth model was developed for projecting hardwood basal area to age 3, which is when release treatments would be applied. Sensitivity analyses examined the relative importance of site index, interest rate, pine stumpage value, and treatment cost in determining economic thresholds. The most important biological factor was site index, and interest rate was the most important economic factor. Pine stumpage value and cost of hardwood control treatment were relatively unimportant in determining economic thresholds.

INTRODUCTION

Control of competing vegetation has become a common silvicultural practice for managing pine plantations in the Southeast. Budgetary and environmental considerations require that vegetation management treatment be prescribed on the basis of site-specific analysis of costs and benefits. To be most effective, vegetation treatments must be applied at young ages. However, information on the long-term benefits of vegetation management is inadequate, and response to different treatments cannot be reliably extrapolated to rotation age as required for economic analyses.

Research over the last 25 years has shown substantial increases in pine growth following hardwood control (Clason 1978, Cain and Mann 1980, Glover and Dickens 1985, Glover and Zutter 1993, Miller and others 1995, Quicke and others 1996). Despite these efforts, forest managers have few quantitative tools to assess "how much is too much" for specific site and stand conditions. According to Wagner (1993), developing objective and quantitative systems to evaluate the response to proposed treatments is one of the highest priorities for vegetation management research. Such decision support tools are needed to ensure that treatments are prescribed only when the long-term changes in stand development can be economically justified and balanced with ecological considerations (Wagner 1994).

The economic threshold—the hardwood density at which the discounted value of the gain in timber volume at rotation age following a competition control treatment equals the discounted cost of the competition control treatment (Cousens 1987)—serves as a basis for justifying vegetation treatments. The economic threshold approach involves computing net present value (NPV) for competition control treatments and determining the level of hardwood competition that produces an NPV of \$0/ac in the treated stand.

$$\mathrm{NPV} = \frac{\text{Volume Gained} \times \text{Stumpage Value}}{(1+i)^r} - \frac{\text{Treatment Cost}}{(1+i)^t} = 0 \quad [1]$$

where i=interest rate (percent), r = rotation age (years), and t = age of hardwood control treatment (years). Estimating the volume gained following competition control is essential to computing the economic thresholds.

The method of determining the economic threshold level of hardwood competition consists of 3 steps, and is demonstrated for loblolly pine plantations. Yield is simulated for various levels of site index, planting density, and HBA. The second step is to use predicted yield, pine stumpage value, hardwood treatment cost, and interest rate to compute the economic threshold level of hardwood competition at rotation age. The final step is to project the economic threshold level of hardwood competition at rotation age to the age when a release treatment would be applied. Sensitivity of biological factors (site index and planting density) and economic factors (interest rate, pine stumpage value, and treatment cost) on the economic threshold level of hardwood competition also is examined.

[1]Assistant Professor, Department of Forestry, Wildlife and Fisheries, University of Tennessee, Knoxville, TN 37901-1071.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

METHODS

Predicted Yield

The first step in determining economic thresholds is to predict the yield of loblolly pine plantations with varying amounts of hardwood competition. Three computer models have been developed (Burkhart and Sprinz 1984, Smith and Hafley 1986, and Knowe 1992) to simulate the effects of hardwood competition in loblolly pine plantations. Knowe (1992) compared the assumptions and methodology of these yield systems. Data used to develop the models were obtained primarily from Piedmont and Upper Coastal Plain sites. When hardwood competition is present, all three existing models produce negatively skewed diameter distributions, with predominately small-diameter trees and few large-diameter trees. These models use a negative exponential relationship between pine basal area and percent HBA: greater pine reductions occur at low levels of hardwood competition than at high levels.

A major limitation of all three existing models is that percent HBA is used as a predictor variable. Pine basal area can be obtained from total basal area and percent HBA. Furthermore, total basal area must be known in order to compute percent HBA. Therefore, using percent HBA implies that the basal area of both the pine and hardwood components is known. In addition, the long-term dynamics of percent HBA are not well documented, with one notable exception (Glover and Zutter 1993), and it cannot be reliably predicted (Harrison and Borders 1996).

A major difference in the loblolly pine plantation yield prediction systems is the amount of pine basal area displaced by hardwood competition. The Burkhart and Sprinz (1984) model implies that 1 ft²/acre of HBA replaces 1.26 ft²/acre of pine basal area at 10 percent HBA and 2.11 ft²/acre of pine basal area at 30 percent HBA. The model developed by Smith and Hafley (1986) implies replacement ratios of 0.88 ft² and 0.93 ft² of pine basal area per ft² of HBA at 10 and 30 percent HBA, respectively. The Knowe (1992) model implies a replacement ratio of 0.97:1 (ft² pine basal area/ft² hardwood basal area) at 10 percent HBA and 0.99:1 at 30 percent HBA.

The pine basal area and diameter distribution models developed by Knowe (1992) were chosen for demonstrating the method of computing economic threshold level of hardwood competition. The pine basal area model was refit by using absolute HBA rather than percent HBA. The resulting equation accounted for only 1.5 percent less of the variation in observed pine basal area than the model with percent HBA. Dominant height, survival, individual tree height, and volume were predicted by using the functions developed by Borders and others (1990).

Loblolly pine yield at age 25 years was simulated using 0, 5, 10, 15, 20, and 25 ft²/acre of HBA in stands with site index (base age 25) values of 50 to 80 feet, in 5-foot increments, and planting densities of 500-900 trees/acre, in increments of 100 trees/acre. The relationship between loblolly pine yield and hardwood basal area was linear for all combinations of site index and planting density, so simple linear regression models were developed for each level of site index and planting density:

$$Y = b_0 - b_1 HBA \quad [2]$$

where Y = loblolly pine yield (tons/acre) at age 25 and HBA = hardwood basal area (ft²/acre). Inspection of the intercepts (b_0) and slopes (b_1) for all 30 combinations of site index and planting density indicated a linear relationship with site index but no relationship with planting density.

The final step is to project the economic threshold level of hardwood competition at rotation age (25 years) to an age when a release treatment would be applied. In this example, release treatments were applied at age 3 years. As previously mentioned, long-term data on hardwood basal area growth in loblolly pine plantations is very limited. The one notable exception involves a well-documented site preparation study in the upper Coastal Plain of Alabama

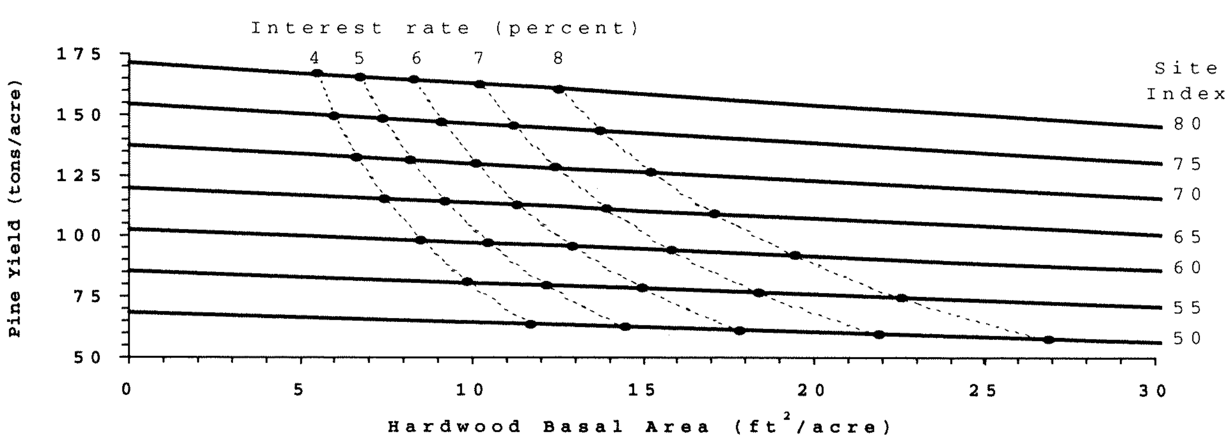


Figure 1—Relationship between loblolly pine yield and hardwood basal area at age 25 for site index between 50 and 80. The dashed lines represent the economic threshold level of hardwood basal area for interest rates between 4 and 8 percent. Additional inputs: pine stumpage value = $30/ton and hardwood control treatment cost = $60/acre.

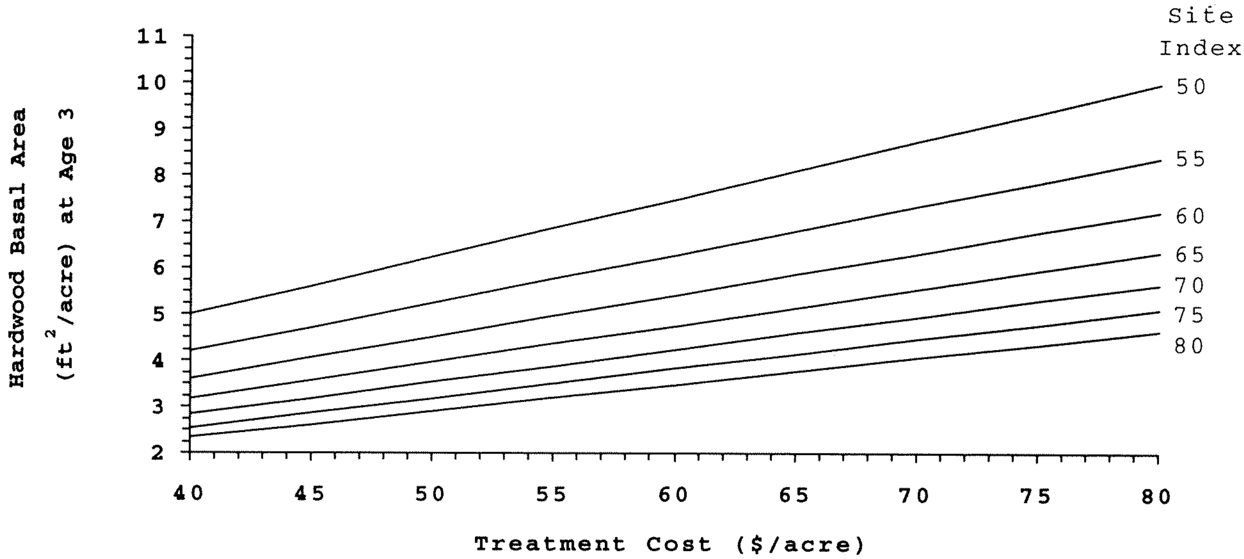


Figure 2—Economic threshold level of hardwood basal area at hardwood control treatment age 3 years for interest rates between 4 and 8 percent. Additional inputs: pine stumpage value = $30/ton and hardwood control treatment cost = $60/acre.

(Glover and Zutter 1993). This study included 5 replications of an untreated check plus chemical (injection and two methods of cut-surface treatment), mechanical (bulldozer scarification), and manual (girdling) treatments. Surviving hardwoods and resprouts developed along with the planted loblolly pine for 27 years after treatment.

Fifty observations of average HBA for each of the six site preparation treatments at ages 1-4, 6, 11, 13, 22, and 24 years were used in the analyses. Data for age 27 were excluded from the regressions because hardwood basal area growth was negative between ages 24 and 27 years for several treatments, and a more complex equation would be required to describe this downward trend. In addition, hardwood data were not available for one of the cut-surface treatments at plantation ages 11 and 13 years. Observed HBA-age pairs for each treatment were arranged into 45 non-overlapping growth intervals (e.g., ages 1-2, 2-3, 3-4, 4-6, 6-11, etc.). Graphs of these data suggested several potential equations for describing the observed patterns of HBA growth. Tests for differences in the growth rates among site preparation treatments were also conducted by incorporating indicator variables into the equation that best fit the observed data.

Statistical differences in hardwood growth rates were detected among the site preparation treatments. Average growth rate for the herbicide treatments (injection only, girdle+herbicide, and chain frill+herbicide) was slower than for the non-herbicide treatments (no treatment, girdle only, and bulldozer scarification). However, this difference was not of practical importance because the equation with treatment-specific growth rates accounted for only 0.3% more of the variation in projected HBA than the reduced model. A single equation can be used to predict hardwood basal area (HBA_X) at any plantation age (X) using current hardwood basal area (HBA) and current age (Age):

$$HBA_X = HBA \exp\{0.0395^*(X\text{-}Age)\}. \quad [3]$$

This equation accounted for 98% of the variation in projected HBA. In this example, the economic threshold level of hardwood basal at a rotation age of 25 years is projected to a hardwood-control treatment age of 3 years by multiplying HBA at rotation age by 0.4194. This implies that about 42 percent of the HBA at 25-year-old stands is present in 3-year-old stands, when release treatments are applied.

Sensitivity Analyses

The sensitivity analysis was conducted for two reasons. The first is to examine predictions at extreme values of input variables to determine whether the model and assumptions are reasonable. The second reason is to assess the relative importance of biological and economic factors used in determining economic thresholds. Economic factors included in the sensitivity analyses were interest rates of 4 to 8 percent; pine stumpage values of $25/ton to $35/ton; and hardwood treatment costs of $50/acre to $90/acre. The relative importance of the biological and economic factors was examined by varying one factor while holding the remaining factors constant. The more influential factors result in greater variations in the economic threshold level of HBA than the less important factors.

RESULTS

Linear relationships were observed between the intercepts (b_0) and slopes (b_1) of the yield equation in [2] and site index for all combinations of site index and planting density. Therefore, loblolly pine yield at age 25 in [2] can be generalized as:

$$Y = [-103.0979+(3.4325\ SI)]-[0.3709-(0.0155\ SI)]xHBA \quad [4]$$

where SI = site index (base age 25) and other terms as previously defined. Volume gained following competition

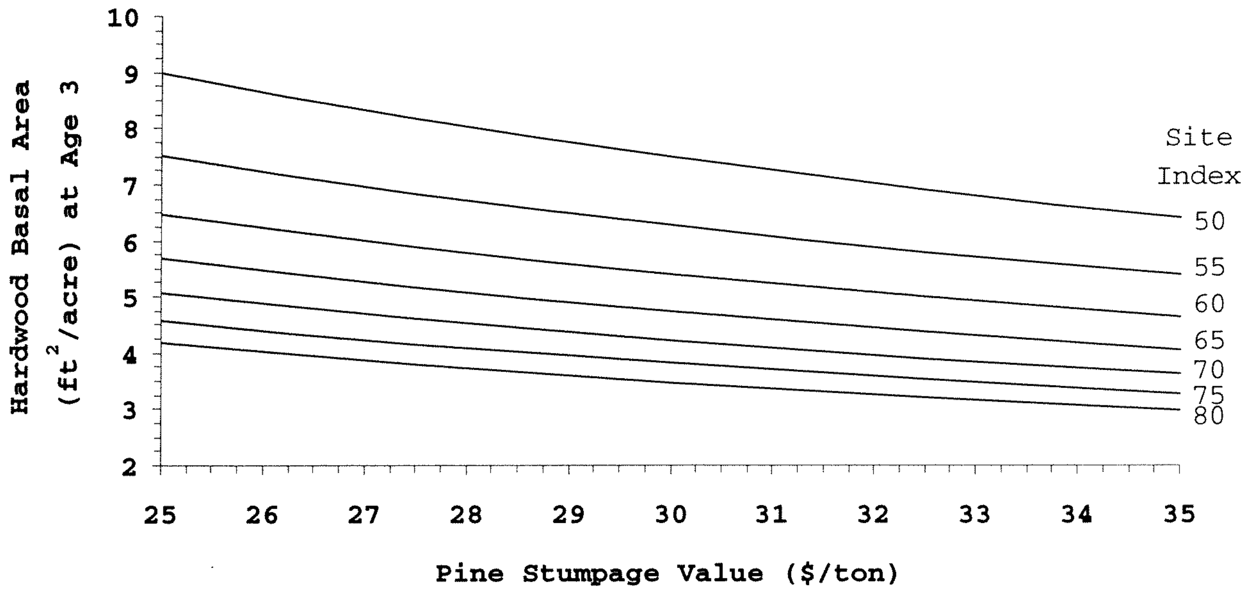


Figure 3—Economic threshold level of hardwood basal area at hardwood control treatment age 3 years for pine stumpage values between $25/ton and $35/ton. Additional inputs: interest rate=6 percent and hardwood control treatment cost=$60/acre.

control (VG) is the difference in yield for stands without hardwoods (HBA = 0) and stands with hardwoods. Combining [2] and [4], VG is:

$$\begin{aligned} VG &= [b_0 - b_1(0)] - [b_0 - b_1(HBA)] \qquad [5] \\ &= [b_0 - b_0] + b_1(HBA) \\ &= b_1(HBA) \\ &= [-0.3709 + (0.0155 x SI)] x HBA \end{aligned}$$

Note that the sign of b_1 changes from negative in [4] to positive in [5], which changes the sign of the component coefficients. When response to hardwood control is expressed as b_1HBA, the economic threshold level of hardwood basal area (HBA_{ET}) for a 25-year rotation (r = 25) and hardwood control treatment at age 3 (t = 3) can be computed by solving [1] for HBA as follows:

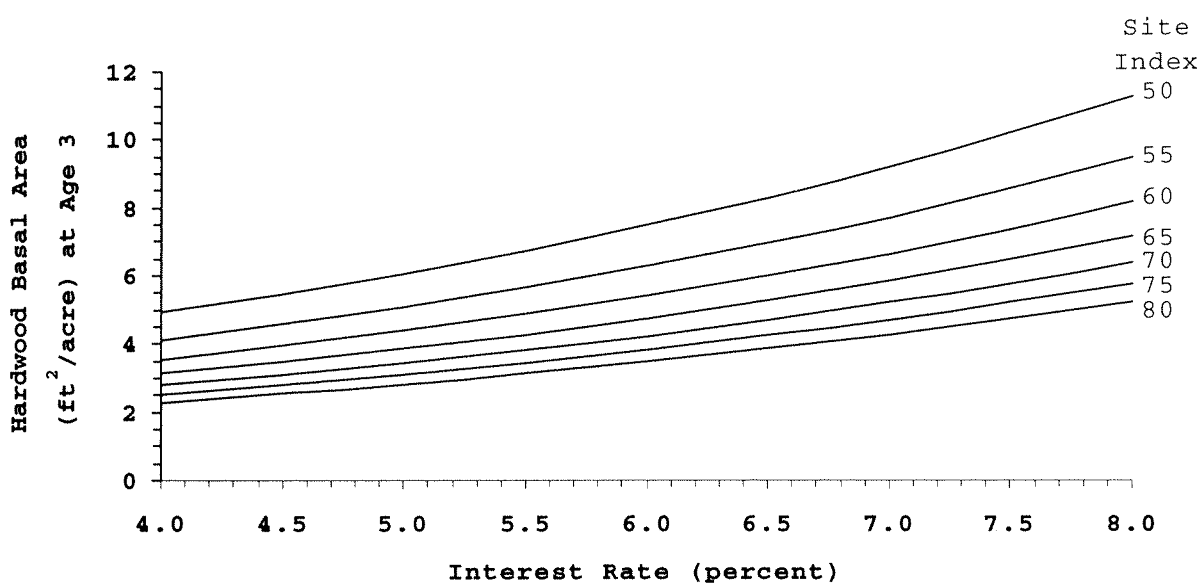


Figure 4—Economic threshold level of hardwood basal area at hardwood control treatment age 3 years for hardwood treatment costs between $40/acre and $80/acre. Additional inputs: interest rate=6 percent and pine stumpage value=$30/ton.

$$HBA_{ET} = \frac{TC \times (1+i)^{22}}{SV \times [-0.3709 + (0.0155 \times SI)]} \qquad [6]$$

where i = interest rate, SV = pine stumpage value ($/ton), TC = hardwood treatment cost ($/acre), and r-t = 22 years. The economic threshold level of hardwood basal at rotation age is projected to a hardwood-control treatment age of 3 years by multiplying HBA at rotation age by 0.4194.

The effect of varying interest rate on economic threshold level of hardwood basal area at age 25 is shown in figure 1 for fixed pine stumpage value and hardwood treatment cost. As expected, yield increases with increasing site index and decreases with increasing HBA. When interest rate = 6 percent, site index = 65, pine stumpage value = $30/ton, and treatment cost = $60/acre, for example, the economic threshold hardwood basal area is about 11.5 ft²/acre and expected yield is about 112 tons/acre. The difference in yield between interest rates is not equal, and is larger at lower site index than higher. This implies an interaction between interest rate and site index.

Multiplying HBA at rotation age by 0.4194 provides an estimate of HBA at age 3, which is when hardwood control treatments would be prescribed (figure 2). Using the previous example, the economic threshold hardwood basal area is about 4.7 ft²/acre at age 3. This is interpreted as the minimum amount of hardwood competition that must be present for a $60/acre release treatment to be financially attractive under those circumstances.

The effect of varying pine stumpage value on economic threshold level of hardwood basal area at age 3 is shown in figure 3 for fixed interest rate and hardwood treatment cost. In this case, the economic threshold level of hardwood basal area decreases with increasing pine stumpage value and site index. For example, when pine stumpage value = $30/ton, site index = 65, interest = 6 percent, and treatment cost = $60/acre, the economic threshold hardwood basal area is about 4.7 ft²/acre. The difference in economic thresholds across pine stumpage values is nearly linear, and the difference is larger at lower site index than at higher site index.

The effect of varying hardwood treatment cost on economic threshold level of hardwood basal area at age 3 is shown in figure 4 for fixed interest rate and pine stumpage value. As with interest rates, the economic threshold level of hardwood basal area increases with increasing treatment cost and decreasing site index. When treatment cost = $60/acre, site index = 65, interest = 6 percent, and pine stumpage value = $30/ton, the economic threshold hardwood basal area is about 4.7 ft²/acre. The difference in economic thresholds across hardwood treatment costs is nearly linear, and the difference is larger at lower site index than at higher site index.

DISCUSSION AND SUMMARY

The concept of economic thresholds was applied to hardwood competition in loblolly pine plantations, and procedures were developed for estimating threshold levels of hardwood basal area. The sensitivity analysis of biological and economic factors affecting the threshold level of hardwood basal area indicated that both interest rate and site index were more influential factors than stumpage value and treatment cost.

Interest rate has the greatest influence on economic thresholds, especially on poor sites. A 1 percent increase in interest rate increases threshold by 1-2 ft²/acre on good sites and by 5 ft²/acre on poor sites. A $5/acre increase in treatment cost increases economic threshold level of hardwood basal area by 0.50 ft²/acre on good sites and by 0.75 ft²/acre on poor sites. Increasing loblolly pine stumpage value decreases threshold by 0.5 ft²/acre on good sites and by 1.0 ft²/acre on poor sites.Growth models used to simulate hardwood competition may have profound effects on the biological and economic interpretations. The pattern of negative exponential response of pines to hardwood competition implies that low levels of hardwood basal area would produce a greater proportional reduction in pine yield than at higher levels of hardwood competition. Thus, the Burkhart and Sprinz (1984) model may be more appropriate at low levels of hardwood basal area while the Knowe (1992) model may be more appropriate at the higher levels of hardwood competition. Additional considerations are the pine:hardwood replacement ratio and hardwood dynamics. A more comprehensive pine release dataset, with hardwood information, is needed to refine the economic threshold method presented in this study.

ACKNOWLEDGMENTS

Tom Fox, Tim Harrington, Steve Radosevich, Barry Shiver, and Bob Wagner helped to develop the economic threshold concept.

REFERENCES

Borders, B.E.; W.M. Harrison; D.E. Adams; R.L. Bailey; L.V. Pienaar. 1990. Yield prediction and growth projection for site-prepared loblolly pine plantations in the Carolinas, Georgia, Florida, and Alabama. Plantation Manage. Res. Coop. Tech. Report 1990-2, Athens, GA: School of Forestry Resources, Univ. of Georgia. 65 p.

Burkhart, H.E.; P.T. Sprinz. 1984. A model for assessing hardwood competition effects on yields of loblolly pine plantations. Publ. No. FWS-3-84, Blacksburg, VA: School of Forestry and Wildlife Resources, VPI&SU. 55 p.

Cain, M.D.; W.F. Mann, Jr. 1980. Annual brush control increases early growth of loblolly pine. Southern Journal of Applied Forestry. 4: 67-70.

Clason, T.R. 1978. Removal of hardwood vegetation increases growth and yield of a young loblolly pine stand. Southern Journal of Applied Forestry. 2: 96-97.

Cousens, R. 1987. Theory and reality of weed control thresholds. Plant Protection Quarterly. 2(1): 13-20.

Glover, G.R.; D.F. Dickens. 1985. Impact of competing vegetation on yield of southern pines. Ga. For. Res. Pap. 59. 14 p.

Glover, G.R.; B.R. Zutter. 1993. Loblolly pine and mixed hardwood dynamics for 27 years following chemical, mechanical, and manual site preparation. Canadian Journal of Forest Research. 23: 2126-2132.

Harrison, W.M.; B.E. Borders. 1996. Yield prediction and growth projection for site-prepared loblolly pine plantations in the Carolinas, Georgia, Alabama, and Florida. Plantation Manage. Res. Coop. Tech. Report 1996-1, Athens, GA: School of Forestry Resources, University of Georgia. 65 p.

Knowe, S.A. 1992. Basal area and diameter distribution models for loblolly pine plantations with hardwood competition in the Piedmont and upper Coastal Plain. Southern Journal of Applied Forestry. 16: 93-98.

Miller, J.H.; B.R. Zutter; S.M. Zedaker; M.B. Edwards; R.A. Newbold. 1995. A regional framework of early growth response for loblolly pine relative to herbaceous, woody, and complete competition control: The COMProject. Gen. Tech. Rep. SO-117, New Orleans, LA: U.S.Department of Agriculture, Forest Service, Southern Forest Experiment Station. 48 p.

Quicke, H.E.; G.R. Glover; D.K. Lauer. 1996. Herbicide release of 3-year-old loblolly pine from competing hardwoods in Arkansas. Southern Journal of Applied Forestry. 20: 121-126.

Smith, W.D.; W.L. Hafley. 1986. Simulating the effect of hardwood encroachment on loblolly pine plantations.In: Phillips, D.R., comp. Proceedings of the Fourth biennial southern silvicultural research conference; 1986 November 4-6, Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 180-186.

Wagner, R.G. 1993. Research directions to advance forest vegetation management in North America. Canadian Journal of Forest Resources. 23: 2317-2327.

Wagner, R.G. 1994. Toward integrated forest vegetation management. Journal of Forestry. 92: 26-30.

EMPIRICAL ALLOMETRIC MODELS TO ESTIMATE TOTAL NEEDLE BIOMASS FOR LOBLOLLY PINE

Hector M. De los Santos-Posadas and Bruce E. Borders[1]

Abstract—Empirical geometric models based on the cone surface formula were adapted and used to estimate total dry needle biomass (TNB) and live branch basal area (LBBA). The results suggest that the empirical geometric equations produced good fit and stable parameters while estimating TNB and LBBA. The data used include trees form a spacing study of 12 years old and a set of fully measured trees on the coastal plain of North and South Carolina of ages 10 to 25.

INTRODUCTION

One of the most important factors contributing to the development of a stand is the amount of leaf biomass. Although its contribution to total tree biomass is only 4 to 6 percent, leaf biomass is responsible for most of the transpiration-respiration processes and total carbon uptake in the tree (Zhang, 1997). Leaf biomass has proven to be very sensitive to climatic patterns and silvicultural treatments, thus quantification of leaf biomass may be important for explaining productivity of forest stands.

Accurate estimation of leaf biomass may not only improve estimation of the potential growth rate but can be used to characterize other stand conditions. For example leaf area is useful as an index of productivity and vigor that explains a potential source of variability in stand response to silvicultural treatments. O'Hara (1989) states that thinned stands have higher transpiration/respiration rates and require greater sapwood area to supply a given amount of leaf biomass. In this case, the reduction in the number of trees makes more water and nutrients available producing more conductive tissue that remains healthy for more time. This is also true for stands growing on good quality sites.

Leaf biomass and leaf area may become an important input to a new generation of growth and yield models that are more site specific than today's models. It is anticipated that since leaf biomass is sensitive to environmental and silvicultural factors, models that use it to project growth will also be more sensitive to these factors. The most wide spread approach for estimating leaf area and needle biomass is based on allometric relationships. The basic allometric relationship between leaf biomass and stem size (diameter or stem area) is based on the pipe model theory proposed by Shinozaki and others(1964). Based on this work, Waring and others(1981) suggested that the amount of foliage is proportional to the amount of conductive tissue present on the stem, which for conifers is the sapwood. In geometric terms leaf biomass should be related not only to the transversal area but the geometry of the crown.

Several of these studies show that, in general, these allometric relationships are not completely linear or are only linear for a given age class. Most of the equations developed to estimate biomass are linear in logarithmic units or intrinsically non-linear. Baldwin (1989) presented equations to compare the fit of leaf biomass from DBH and the sapwood area (cm^2) at breast height and live crown height, finding that DBH was the best independent variable to estimate needle and branch biomass for loblolly pine. Long and Smith (1988) and Long and Smith (1989) developed non-linear models for *Pinus contorta* and *Abies lasiocarpa* that include crown size observations, making the equations more tree specific and sensitive to stand density. McCrady and Jokela (1998) used the pipe model theory and assume that leaf biomass is proportional to total tree volume suggesting that the amount of leaf area/leaf biomass is strongly related with the geometry of the tree biomass.

The main objective of this study is to develop site/tree specific allometric needle biomass prediction equations such that the total tree dry needle biomass (TNB) prediction equations are sensitive to stand density and stand structure. The new models should improve leaf area estimation and provide a means of differentiating total stand biomass growth for stands that have similar size stem dimensions but different amounts of leaf biomass.

MATERIALS AND METHODS

The research was conducted in a loblolly pine spacing study established at the B.F Grant Memorial Forest near Eatonton, Georgia (Pienaar and others, 1997). The study was planted with genetically improved seedlings in March 1983 at a 6 by 6 ft spacing (1.81 by 1.81 m). In July 1983, 24 one fifth-acre treatment plots each with a one-tenth acre interior measurement plot (0.08 ha) were installed with planting densities of 100, 200, 400 600, 800 and 1000 trees per acre (247, 494, 988, 1483, 1977 and 2471 tress per hectare, respectively). The experimental plots were completely randomized with four replications of each density. The study is located on an old agricultural field

[1]Graduate Student, Professor, D.B. Warnell School of Forest Resources, University of Georgia, Athens, GA 30602-2152, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

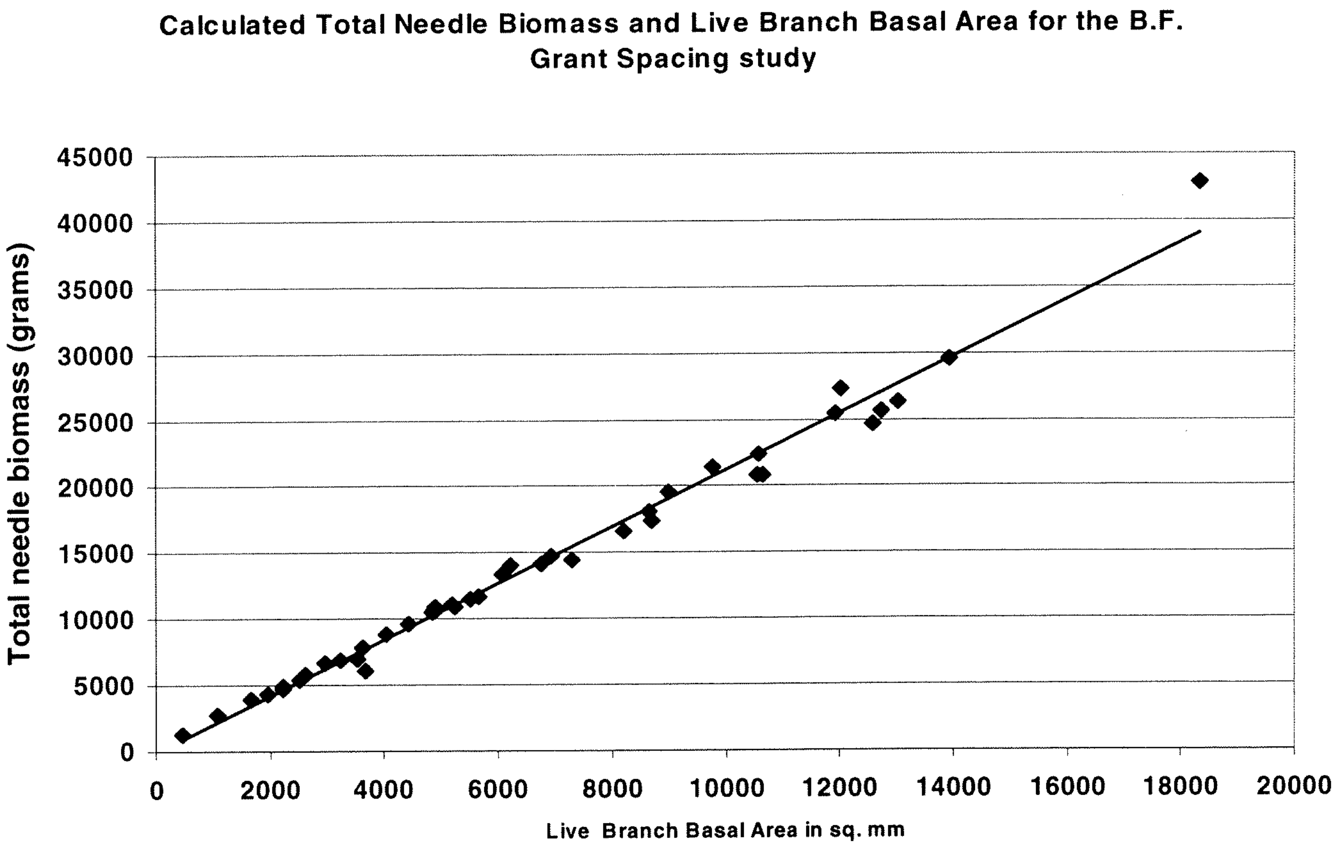


Figure 1— Total Dry Needle Biomass (TNB) vs Live Branch Basal Area (LBBA) for the B. F. Grant spacing study.

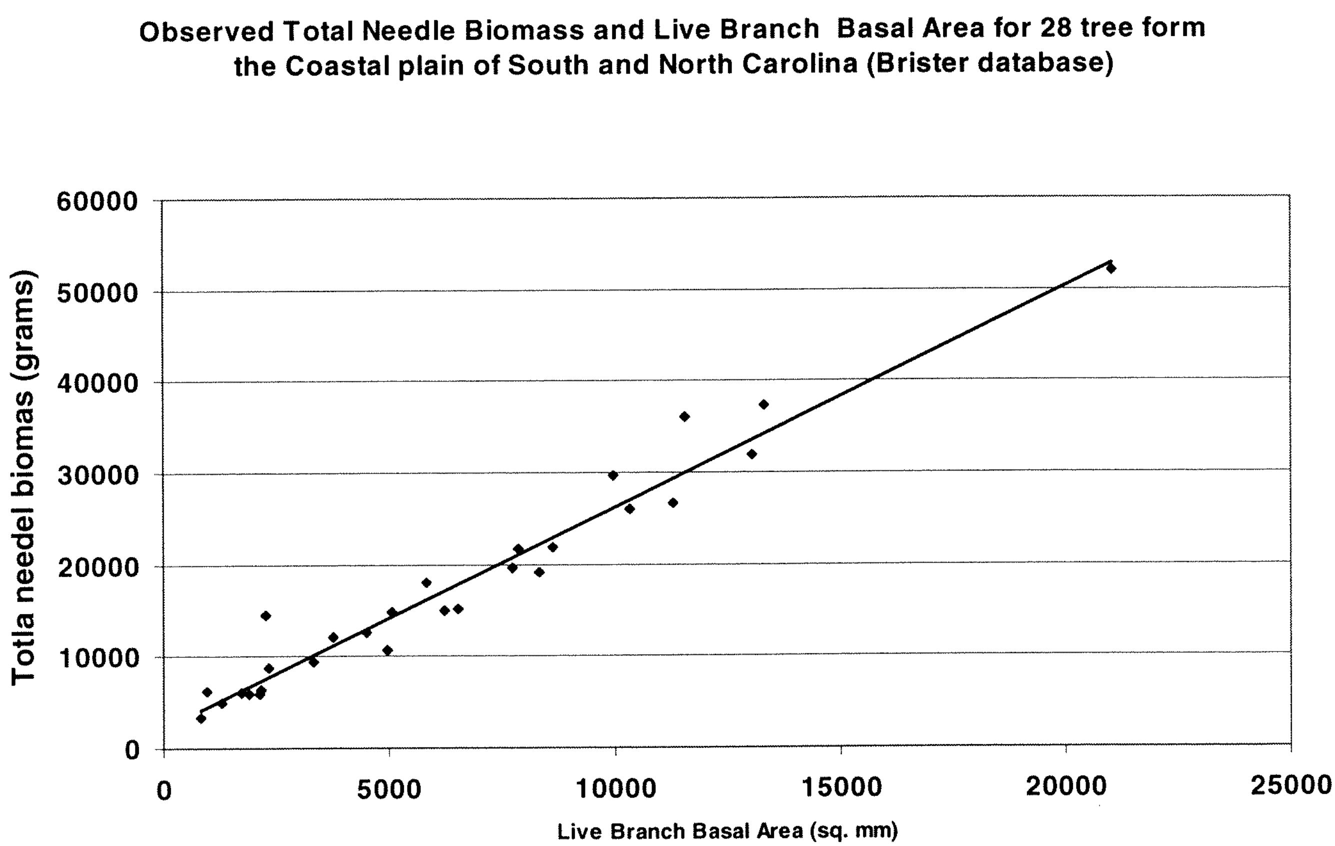


Figure 2— Total Dry Needle Biomass (TNB) vs Live Branch Basal Area (LBBA) for the Brister database on the Coastal plain of North and South Carolina.

which had been previously planted with soybeans. Herbicide was first applied in May 1984 and in 1985, wildlings of both loblolly pine and sweetgum (*Liquidambar styraciflua*) were mechanically removed in 1985. As a result all the plots have been growing essentially free of competing vegetation throughout the life of the study.

In July 1997 felled trees from the first thinning of the B. F. Grant spacing study were sampled to produce needle biomass estimators. Trees from all plots, except the 247 trees/ha plots, were cut to reach a residual target number of trees. The thinning was primarily from below, however good spatial distribution of residual stems was also a criterion for tree selection. Forty-three trees were selected and sampled using the methodology described by Xu (1997) to develop a two-level allometric estimation procedure: equations based on branch measurements were used to estimate dry needle branch biomass and in turn other equations were used to estimate total tree dry needle biomass. Sample trees came from four crown classes: dominant (12), co-dominant (21), intermediate (8) and suppressed (2). The selected trees were free of deformities and fusiform rust.

The variables measured for each tree include diameter at breast height (D) in cm, total height from the stump in m, stump height in m, and live crown height in m. The crown also was carefully measured and divided in five equal length sections along the stem. One branch was randomly taken in each section and the parts of the branch with foliage were collected, identified for tree and section number and bagged for further laboratory analysis. For each sample, branch length (m) and basal branch diameter (mm), at approximately 20 mm from the base of the branch, were obtained with a measuring tape and a digital caliper, respectively. The branch height (BH) and basal branch diameter (BBD) for every live branch was also recorded.

In the laboratory, the foliage of each sample branch was separated from the branch fragment, identified, and dried at 70° C until reaching a constant weight. The needle weight was then measured with a balance to the nearest gram. An additional database from a similar study on loblolly pine was provided by Professor Graham H. Brister and used to test the models by estimate LBBA and TNB per tree.

RELATIONSHIP BETWEEN TOTAL NEEDLE BIOMASS AND LIVE BRANCH BASAL AREA

In an attempt to increase the precision of estimation for total dry needle biomass for the entire tree the relationship between the total dry needle biomass (TNB) and the total live branch basal area in mm^2 (LBBA) was analyzed. Graphical analysis shows (figure 1) that this relationship is very strongly linear and stable for the trees in this study. This behavior is logical since branch needle biomass was estimated with a linear equation that uses the branch diameter squared (De los Santos, 1998). To verify this relationship a database generated by Brister in 1977 for 28 loblolly pine trees was used (figure 2). All trees in this database were located in the coastal plain of North and South Carolina and total needle biomass was obtained by removing and weighing all needles in each branch. Clearly the relationship between LBBA and the observed TNB is very similar to the relationship observed for the 43 trees in the B. F. Grant spacing study. A similar relationship was found by Whitehead (1990) in *Pinus radiata* for branch basal area and leaf area clustered on "branch complexes" but was never aggregated to estimate the total leaf area per tree. This relationship seems less appropriate for shade intolerant trees growing at wide spacing and/or old stands that have changed the excurrent growing pattern from the young-middle ages to a more sympodic pattern. In these old age trees the crown expands more longitudinally than vertically, the branches become more massive and ultimately accumulate heartwood.

Regression analysis (table 1) with both databases shows a strong and stable correlation between these two characteristics. The slope of the regression line can be interpreted as the amount of needle biomass sustained by each unit of conductive tissue surface area attached to the stem. The differences in the slope can be attributed in part to the process of allometric estimation versus measured biomass and by differences in site quality and management at each site. Trees in the B. F. Grant spacing study sustain more needle biomass than the sites in the coastal plain which is most likely due not only to differences in nutrient availability but to the amount and types of competing vegetation.

GEOMETRIC MODELS

Since LBBA and TNB are linearly and highly correlated it may be useful to focus on prediction of LBBA using geometric based models. Thus the hypothesis is that LBBA should be proportional to the stem surface area occupied by live crown. The main assumption is that the estimation based on tree characteristics will be more precise for LBBA than for the TNB.

The basic form for the cone surface was modified to be used as empirical models. Since the diameter at the base of the live crown was not obtained, diameter at breast height (D) and crown length (L) are used in these model forms. The constant p was replaced by a scale parameter in the formulations. These structures were motivated by the description that Steill (1964) cited by Seymour and Smith, (1987) used for crown volume for *Pinus resinosa*. He found a very good correlation between foliage weight and crown volume estimated with a paraboloid formula.
The models derived are:

Cone formulation 1

$$(1) \qquad B = a\left(\frac{D}{2}\right) * \sqrt{\left(\frac{D}{4}\right)^b + L^c}$$

Cone formulation 2

$$(2) \qquad B = a\left(\frac{D}{2}\right) * \left[\left(\frac{D}{4}\right)^b + L^2\right]^d$$

Where:

a, b, c and d are the parameters to be estimated,
B = LBBA or some other biomass crown component as needle biomass, all else is as defined above.

Table 1— Analysis of Variance for Total dry needle biomass (TNB) vs Live Branch Basal Area (LBBA) vs. for B.F. Grant spacing study data and North and South Carolina coastal plain (Brister Data) $TNB_i = \alpha + \beta (LBBA_i) + e_i$

B.F. Grant Database

Source	df	SSE	MSE	F Value	Prob > F
		Analysis of Variance			
Regression	1	691369020.8	691369020.8	3049.81	.0000001
Residual	40	9067698.453	226692.4613		
Total	41	700436719.3			

R-square = 0.98705

	Coefficients	Standard Error	t stat	P-value
Intercept	120.8546	139.7541	0.8647	0.392324
Slope	0.4638	0.0084	55.2251	0.00001

Brister Database

Source	df	SSE	MSE	F Value	Prob > F
		Analysis of Variance			
Regression	1	544452712	544452712	497.139	.0000001
Residual	24	26284127.89	1095171.995		
Total	25	570736839.8			

R-square = 0.95394

	Coefficients	Standard Error	t stat	P-value
Intercept	-436.412	382.2230	-1.14177	0.264812
Slope	0.391966	0.01758	22.2966	.0000001

Table 2— Fit statistics and parameter estimates for cone formulation 1 on the B.F. Grant spacing study data

	DF Model	DF Error	SSE	MSE	Root MSE	R-square
TNB	3	40	8348	208.6878	14.44603	0.9278
LBBA	3	40	35465	886.6308	29.77635	0.9304

	Parameter	Estimate	Standard Error	Aprox T ratio	Aprox Prob > |T|
TNB	*a*	15.73783	4.52413	3.48	0.0012
	b	3.456465	0.32257	10.72	0.0001
	c	4.219977	0.3263	12.93	0.0001
LBBA	*a*	30.31826	8.39138	3.61	0.0008
	b	3.61632	0.29436	12.29	0.0001
	c	4.230212	0.33276	12.71	0.0001

Table 3— Fit statistics and parameter estimates for cone formulation 2 on the B.F. Grant spacing study data

	DF Model	DF Error	SSE	MSE	Root MSE	R-square
TNB	3	40	8441	211.0289	14.52683	0.927
LBBA	3	40	35908	897.6995	29.96163	0.9295

	Parameter	Estimate	Standard Error	Aprox T ratio	A prox Prob > |T|
TNB	*a*	12.82514	4.35711	2.94	0.0054
	b	2.450571	0.09015	9.47	0.0001
	c	0.854042	0.24696	9.92	0.0001
LBBA	*a*	23.91818	7.70821	3.1	0.0035
	b	2.278922	0.08229	11	0.0001
	c	0.905521	0.23598	9.66	0.0001

Table 4— Fit statistics and parameter estimates for cone formulation 1 on the Brister Data for the coastal plain of North and South Carolina

	DF Model	DF Error	SSE	MSE	Root MSE	R-square
TNB	3	25	62661312	2506453	1583.2	0.8989
LBBA	3	25	2.61E+08	10431197	3229.7	0.9307

	Parameter	Estimate	Standard Error	Aprox T ratio	Aprox Prob > ITI
TNB	*a*	60.92423	21.79016	2.8	0.0098
	b	2.4915	0.36447	6.84	0.0001
	c	2.238613	0.49897	4.49	0.0001
LBBA	*a*	253.6395	66.22154	3.83	0.0008
	b	1.989328	0.29422	6.76	0.0001
	c	1.942278	0.31365	6.19	0.0001

As density changes it seems logical that tree crown volume changes, adapting its form to the conditions of stand density and competition. Cone formulation 1 above implies that the cone is modified not only by the scale parameter but by changing the form of the arc defined by $(D/4)^b + L^c$. In cone formulation 2 parameter d generalizes the form of the relationship onto a more flexible structure.

The geometric formulations were used to estimate both LBBA and TNB with good results (table 2 and 3) on the spacing study trees. For both formulations the parameters are stable with an acceptable fit. As hypothesized the r-square for LBBA is higher than for the TNB. To correct for effect of heteroscedasticity the following weight function was used

$$W = \frac{1}{D^2 L} \quad (3)$$

MODEL TEST FOR GEOMETRIC MODELS

To test the previous equations 28 trees measured by Brister were fitted with geometric equations to predict TNB and LBBA (table 3 and 4). It is also interesting to notice that estimation of LBBA is better than for TNB as foreseen for this kind of data (total foliage sampled per tree). Note however that the cone formulations show stability on the parameters for both TNB and LBBA fit. In this case no effect

Table 5— Fit statistics and parameter estimates for cone formulation 2 on the Brister Data for the coastal plain of North and South Carolina

	DF Model	DF Error	SSE	MSE	Root MSE	R-square
TNB	3	25	62471770	2498871	1580.8	0.8992
LBBA	3	25	2.61E+08	10430419	3229.6	0.9307

	Parameter	Estimate	Standard Error	Aprox T ratio	Aprox Prob > ITI
TNB	*a*	55.99056	22.82834	2.45	0.0215
	b	1.708317	0.09752	6.48	0.0001
	c	0.632363	0.41849	4.08	0.0004
LBBA	*a*	255.5783	78.06633	3.27	0.0031
	b	1.957699	0.07653	6.48	0.0001
	c	0.495678	0.32397	6.04	0.0001

of heteroscedastisity is shown in the residual analysis, so the estimates of the model are the regular least squares.

Theoretically the models generated shall produce similar results on the same data range. However validation is needed to better qualify the model behavior at more operative levels using a wider more realistic range of variability.

CONCLUSIONS

The inherent hypothesis of the geometric models suggest that a better knowledge of the surface stem geometry at the crown level may produce better estimates of the TNB, crown biomass and LBBA at tree and stand level. The models generated show stability on their parameters and a predictive ability among the best for loblolly pine at the tree level. These structures should produce reliable and more site specific estimates of photosynthetic tissue.

REFERENCES

Baldwin Jr.; V. C. 1989. Is sapwood a better predictor of loblolly pine crown biomass than bole diameter? Biomass 20: 177-185.

Long J. M.; F. W. Smith. 1988. Leaf area-sapwood area relations of lodgepole pine as influenced by stand density and site index. Canadian Journal of Forestry Reseach. 18: 247-250.

Long J. M.; F. W. Smith. 1989. Estimating leaf area of Abies lasiocarpa across ranges of stand density and site quality. Canadian Journal of Forest Research. 19: 930-932.

McCrady, R. L.; E. J. Jokela. 1998. Canopy dynamics, light interception, and radiation use efficiency of selected loblolly pine families. Forest Science. 44(1): 64-72.

O'Hara, K. L. 1989. Stand growth efficiency in a Douglas fir Thinning trial. Forestry. 62(4): 409-418.

Pienaar, L. V.; B. D. Shiver; W. M. Harrison. 1997. Growth potential of loblolly pine plantations in the Georgia Piedmont: A spacing study example. PMRC Tech. Rep. 1997-1. Plantation Management Research Coop., University of Georgia. Athens, GA. 15 p.

Seymour, R.; D. M. Smith. 1987. A new stocking guide formulation applied to eastern White pine. Forest Science. 33:469-484.

Shinozaki, K.; K. Yoda; K Hozumi· T. Kira. 1964. A quantitative analysis of plant form - The pipe model theory. I. Basic Analyses. Japanese Journal of Ecology. 14: 133-139.

Waring, R.H.; K. Newman; J. Bell. 1981. Efficiency of tree crowns and stemwood production at different canopy leaf densities. Forestry. 54: 129-137.

Whitehead D.; Grace J.C.; Godfrey M.J.S. 1990. Architectural distribution of foliage on in individual *Pinus radiata* D. Don crowns and the effects of clumping on radiation interception. Tree Physiology. 7: 135-155

Xu, M. 1997. Growth efficiency of individual loblolly pine (Pinus taeda l.) as affected by crown morphology, stand characteristics and microenvironment. Athens, GA: University of Georgia. 132p. Ph.D. dissertation.

Zhang, Y. 1997. A physiologically based simulation model for loblolly pine. Athens, GA: University of Georgia. 127p. Ph.D., dissertation.

A MODEL DESCRIBING GROWTH AND DEVELOPMENT OF LONGLEAF PINE PLANTATIONS: CONSEQUENCES OF OBSERVED STAND STRUCTURES ON STRUCTURE OF THE MODEL

J.C.G. Goelz and Daniel J. Leduc[1]

Abstract—As longleaf pine (*Pinus palustris* Mill.) may currently represent as little as 1/30th of its former acreage, restoration within its former range in the southern coastal plain is active. Although the focus of these new plantings is aimed at ecosystem restoration, knowledge of the growth and development of longleaf plantations is essential to allow land managers to evaluate different management options. Stand development in longleaf plantations differs from development of plantations of other southern pines. Longleaf seedlings exist in a grass-stage for a varying period, and longleaf saplings and poles can often exist in an intermediate or suppressed crown class for long periods. Other southern pines do not exhibit this behavior. The consequence of these characteristics is that smooth, unimodal diameter distributions are inappropriate for characterizing longleaf pine stands. We will use alternative methods to describe the diameter distributions of longleaf pine. Depending upon viewpoint, the proposed model structure could be called a nonparametric diameter distribution model, or a diameter class model where a uniform distribution is not employed within a class. The model can also be implemented as an individual tree model, if the user desires. A neural net approach has proved promising for initially allocating trees to diameter classes for unthinned stands. A whole-stand basal area prediction equation ensures consistency between these components.

INTRODUCTION

Longleaf pine stands were once a major component of the southern coastal plain from North Carolina to Texas. Currently, longleaf pine may represent as little as 1/30th of its acreage in pre-colonial times (Franklin 1997). An aggressive planting program has developed to restore the longleaf ecosystem within its former range. Although the focus of that work is aimed at ecosystem restoration, knowledge about the growth and development of longleaf plantations is essential for sound management. Longleaf is well-suited for lower-intensity management, particularly longer rotation ages. Also, longleaf pine is less susceptible to most insect and disease problems than other southern pines (Boyer 1990).

Longleaf pine provides higher-value products, such as poles and pilings, more frequently than the more-abundant loblolly pine (*Pinus taeda* L.), and also has a higher specific gravity. Finally, longleaf pine is desirable because a forest of large, old, widely-spaced trees with a grassy understory is "parklike" and visually attractive to visitors.

Many of the older (30 years or older) plantations of longleaf pine arose in a restoration context that is different than the current situation. Often, longleaf plantations were established in cutover areas that had been repeatedly grazed and burned. The current context of restoration is afforesting agricultural fields or converting cutover stands formerly dominated by loblolly pine or mixed pine and hardwoods.

The silvics of longleaf pine distinguish it from other species in the U.S. (Boyer 1990). Three characteristics affect the stand structure of longleaf stands, and hence the structure of a model to describe longleaf plantations. First, longleaf seedlings exist in a "grass stage" for a varying period. The grass stage is a condition where the terminal bud is at or near ground level, and the needles appear similar to a bunchgrass. Although current management practices can often achieve active height growth of most seedlings in the second growing season, individual seedlings may reside in the grass stage for five or more years. Second, although longleaf is an intolerant species, saplings and poles can often exist in an intermediate or suppressed crown class for long periods. Other southern pines do not exhibit this behavior. Suppressed trees rarely respond to release, although trees with live crown ratios of 30 percent or more in the intermediate crown class do respond (Boyer 1990). Third, prescribed fire is an intrinsic part of longleaf pine management, although current practices restrict fire from plantations of other pine species. Interval between fires is often between 2 and 5 years. Prescribed fire ensures that mortality, though rare, will occur throughout the life of a stand, and will restrict ingrowth of volunteer hardwoods and loblolly pine.

There has been little growth and yield modeling done for plantation-grown longleaf pine. A relatively recent model for natural longleaf stands has been provided by Somers and Farrar (1991). The only existing model for plantation-grown

[1]Principal Forest Biometrician and Computer Specialist, Southern Research Station, Alexandria Forestry Center, 2500 Shreveport Hwy, Pineville, LA 71360-5500, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

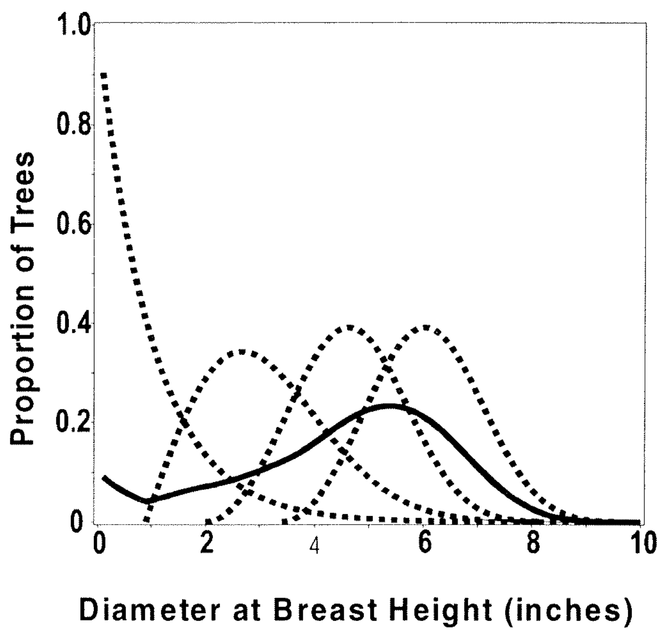


Figure 1—A theoretical diameter distribution represented as a mixture of four populations defined by length of time in the grass stage. The dotted lines represent the four populations, and the solid line is the mixture of these four populations. The proportion of the total is 0.1, 0.2, 0.3, and 0.4 for the four distributions proceeding from the distribution with the smallest mean to the distribution with the largest mean.for natural longleaf stands has been provided by Somers and Farrar (1991). The only existing model for plantation-grown longleaf is restricted to unthinned stands (Lohrey and Bailey 1977). Lohrey and Bailey's work is based on a part of the data available to us; most of those plots have been measured several additional times.

longleaf is restricted to unthinned stands (Lohrey and Bailey 1977). Lohrey and Bailey's work is based on a part of the data available to us; most of those plots have been measured several additional times.

A Theoretical Example

As individual seedlings reside in the grass stage for differing lengths of time, a diameter distribution for longleaf pine can be considered to be a mixture of distributions. The theoretical example in figure 1 suggests a mixture of four distributions: 40 percent of the trees resided in the grass stage for one year, 30 percent for two years, 20 percent for three or four years, and 10 percent for more than four years. Although the diameter distribution for each cohort is smooth, the pooled diameter distribution for the stand is not unimodal. Most commonly-used diameter distribution functions do poorly for stands that have a long, or heavy, left-hand tail, and are incapable of describing multimodality.

A Brief Primer on Alternative Model Structure

Growth and yield models are typically classified into convenient discrete classes. Although such simplistic polychotomies ignore functional similarities among models (see Goelz [in press] for a novel synthesis of modeling structures), we will describe model forms as discrete entities in this brief listing. One distinction is whether growth of individual trees is projected, and whole stand growth is defined by the aggregation of the individual trees, or whether whole-stand variables are directly predicted. When whole stand variables are predicted, the model might disaggregate whole stand growth into a diameter distribution. Intermediate among these are the size class models that project the growth of trees from one size class to another (typically 1 or 2 inch wide dbh classes). Potentially, there are intermediate structures between these classes (Goelz [in press]).

OUR APPROACH TO MODEL STRUCTURE

We believe that model structure should be determined by the needs of the eventual users of the model, the idiosyncracies of the biology of the system to be modeled, and the data available for estimation of the model. For example, if all trees were of uniform value per unit volume, a whole stand type model would be appropriate. On the other hand, if value of the trees varied with species, size, and tree grade (and if these variables were not highly correlated), then an individual tree model might be suggested. If diameter tends to exhibit relatively smooth unimodal distributions, a diameter distribution model might be suggested; if diameter distributions tend to be irregular or multimodal, use of a parametric distribution function may be inappropriate.

Our Data

Our data are described in Goelz and Leduc [in press]. Over 250 plots are scattered from Texas to Alabama and each records over 20 years of stand dynamics. While technically arising following clearcutting natural stands, the areas were often repeatedly burned and grazed for many years before the plantations were planted. Thus, previous use for many of our plots was open-range grazing rather than forest or cropland. The oldest plantations in our database were last measured at age 65.

Example Diameter Distributions from our Data

We provide several diameter distributions from our plots in figure 2. The plots vary considerably. Some resemble the classical unimodal diameter distributions for even-aged stands (e.g. plot A). Others are very irregular, often being bi- or multi-modal (e.g. plot C, age 65). A distinct grass stage, or the vestige of trees that lingered in the grass stage, is evident in some of the graphs (e.g. plots B, C, D). In some cases, thinning encouraged bimodality as thinning was from below, but only merchantable (greater than 4 in. dbh) trees were removed. In other cases, thinning removed a long left-hand tail or subsidiary mode of the distribution. These example diameter distributions suggest that diameter distributions for longleaf plantations take various shapes, many of which do not comply with standard parametric distributions, and thus we will not use standard parametric distributions in our model for longleaf pine.

A Tentative Model Structure

The objectives for our model structure are to: (1) allow for varied diameter distributions, and potentially maintain those structures; (2) allow stand structure, rather than simply whole-stand variables, to influence growth projections; (3) allow relatively simple implementation (at least to the user); (4) allow the model to be invoked as an individual tree model, diameter distribution model, or diameter class model to facilitate use by different clientele; (5) be applicable to inventory data tallied by diameter classes; (6) make extrapolations reasonable by being conditioned by a whole-stand basal area prediction equation; (7) be tractable for investigating optimal stand management. Regarding the use in extrapolation, although our oldest data are from 65 year old plantations, rotation age for longleaf may be as long as 150 years for some managers. To achieve these objectives, we suggest the following structure:

(1) Initially allocate trees into fixed-width diameter classes.
(2) Generate a diameter distribution that is a quadratic polynomial within a diameter class, but is discontinuous at the limits of each diameter class. Thus the diameter distribution consists of a number of pieces.
(3) Adjust number of trees in each class using an individual tree mortality function.
(4) Adjust/recalculate the parameters of the quadratic polynomial to reflect the effects of mortality.
(5) Use an individual tree diameter growth equation to project the limits of the now varying-width diameter classes.
(6) Adjust the growth in tree basal area to be consistent with a whole-stand basal area growth equation.
(7) Adjust the parameters of the quadratic polyno mial using a simple transformation.
(8) Integrate (using appropriate limits of integra tion) the within-class diameter distributions to reconstitute a fixed-width diameter distribution.

These integrals are simple analytic integrals. The definite integrals will define movement ratios (or growth-index

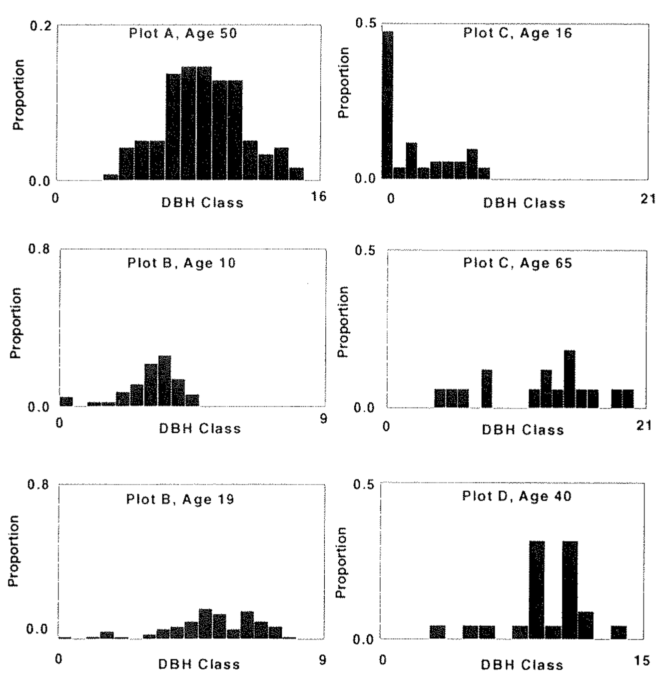


Figure 2—Six observed diameter distributions
variability among diameter distribution shapes within the data.

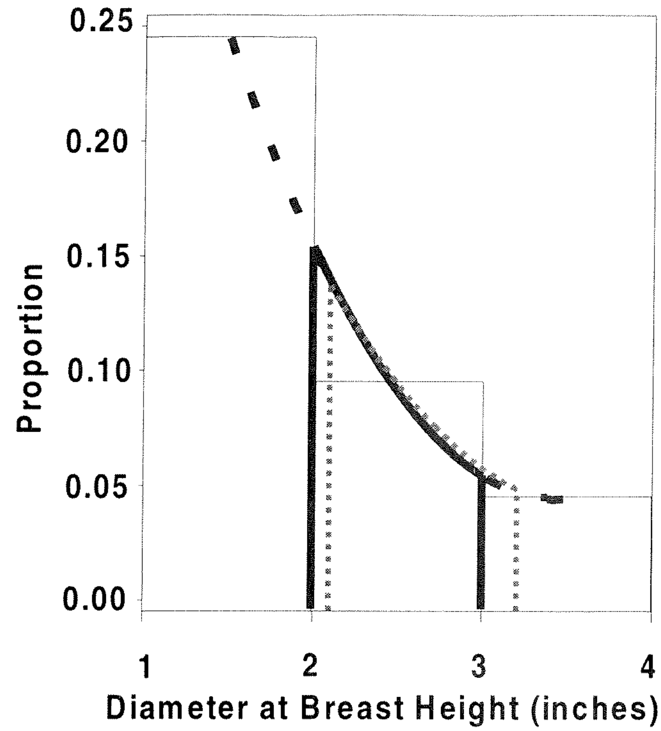


Figure 3—Example of projecting a diameter class into the future. The initial within-class distribution is a simple quadratic polynomial constrained to pass through the midpoints of the adjacent classes (solid lines) and integrate to the area of the histogram within the class. After projection (dotted line), the limits of the diameter class are changed, but the line still integrates to the same area.

ratios) in a diameter class (or stand table projection) model context.

Alternatively, the model could be implemented as an individual tree model, as the component parts are included in this model.

Figure 3 describes some of these steps. To avoid redundancy, we are starting with a diameter distribution that already reflects mortality. The quadratic polynomial ($Y = b_0 + b_1X + b_2X^2$; the math is easier if X is set equal to diameter minus the lower limit of the one-inch diameter class) is constrained to pass through the midpoint of the previous and succeeding diameter classes, and to integrate to the known probability within the diameter class. This is simple to ensure, as there are three parameters of the quadratic equation, and there are three pertinent known values, the proportion of trees in the subject, preceding, and succeeding diameter classes.

If we consider the lower limit of the diameter class to be 0, and the upper limit to be 1, and thus the midpoint of the previous diameter class to be –0.5 and the midpoint of the subsequent diameter class to be 1.5, we have three equations and three unknowns:

$$p_{i-1} = b_0 - \frac{b_1}{2} + \frac{b_2}{4} \qquad [1]$$

$$p_{i+1} = b_0 + \frac{3b_1}{2} + \frac{9b_2}{4} \qquad [2]$$

$$p_i = b_0 + \frac{b_1}{2} + \frac{b_2}{3} \qquad [3]$$

where p_{i-1} is the proportion of trees in the previous diameter class, p_{i+1} is the proportion of trees in the succeeding diameter class, and p_i is the proportion of trees in the diameter class of interest. Equation [3] is the definite integral of the quadratic polynomial from 0 to 1. Equation [1] is obtained by setting Y of the quadratic polynomial equal to p_{i-1} and X equal to –0.5, and equation [2] is obtained by setting Y equal to p_{i+1} and X equal to 0.5. The parameters of the equation can be solved analytically to provide:

$$b_0 = \frac{9}{11} p_i - \frac{7}{44} p_{i+1} + \frac{15}{44} p_{i-1} \qquad [4]$$

$$b_1 = \frac{12}{11} p_i + \frac{1}{22} p_{i+1} - \frac{23}{22} p_{i-1} \qquad [5]$$

$$b_2 = -\frac{12}{11} p_i + \frac{6}{11} p_{i+1} + \frac{6}{11} p_{i-1} \qquad [6]$$

In the case when the diameter class of interest is bounded by 0.0, then b_2 equals zero and equation [1] is not needed.

In that case, b_0 equals $\frac{3p_i - p_{i+1}}{2}$, and b_1 equals

$p_{i+1} - p_i$ if one-inch-wide diameter classes are employed.

When future condition of the diameter class is projected, the limits of the diameter class are predicted with an individual tree diameter growth equation. As larger trees grow more than smaller trees, the width of the diameter class expands. In our example, we used a diameter growth equation that was constrained to be consistent with whole-stand basal area growth, however this constraint could be invoked later. The parameters of the new within-class distribution are obtained by a simple transformation and another solution need not be calculated.

For example, if x is a given diameter within a diameter class with x_0 as the lower limit and x_1 as the upper limit, then the initial distribution might be:

$$f(x) = b_0 + b_1(x - x_0) + b_2(x - x_0)^2 \qquad [7]$$

and after projecting future conditions of the limits of the diameter class (indicated by the additional subscript, $_2$):

$$f(x_2) = \frac{b_0}{(x_{12} - x_{02})} + \frac{b_1}{(x_{12} - x_{02})}\left(\frac{x - x_0}{x_{12} - x_{02}}\right) + \frac{b_2}{(x_{12} - x_{02})}\left(\frac{x - x_0}{x_{12} - x_{02}}\right)^2 \qquad [8]$$

Equation [8] is a simple transformation to ensure integration to the same proportion for that diameter class. To recover a fixed-width diameter distribution, the transformed equation is integrated from the lower level of the projected diameter class to the upper level of the previous fixed-width diameter class (3 inches in the example given in figure 3). That obtains the trees that remained in the same diameter class. Then, the number that moved up into the next diameter class may be obtained by subtraction, or by integration from the upper limit of the previous fixed-width class to the upper limit of the variable-width class. The method is applicable to situations when all trees of a diameter class move one or two classes, or even when trees of an initial fixed-width diameter class are projected to occur in three or more of the fixed-width classes at the end of the projection period. Although this procedure may seem somewhat involved, all of the math can be directly calculated without resorting to numerically solving for the parameters.

Initial Conditions

Although the preceding model structure can project the growth of stands of varying structure, there is no provision for initial conditions when the model will be applied to a "bare ground" starting point. Leduc and others [in press] has applied neural networks to predicting diameter distributions for longleaf pine plantations. We will also apply neural nets to provide the initial diameter distribution for a stand. This module of the model will be applicable to ages of 5 to 20 years. Although Leduc and others. applied neural networks to a much broader range of ages, the technique is less suited for the projection of future conditions, given some initial conditions, as it would be difficult to ensure that illogical behavior was avoided (such as abrupt shifts of diameter distributions within relatively short time periods). We will condition the neural net predictions of trees per acre in each diameter class to be consistent with the whole-stand basal area prediction equation that will also be used in projection. Thus, the basal area prediction equation will link the initial condition and projection components of the model, and will provide consistency.

CONCLUSION

This structure secures all of the objectives stated previously while no standard methodology does so. It could be considered to be an integration of standard diameter distribution models (although with a nonparametric distribution) and individual tree forest models, as well as evocative of "enhancements" to standard size class models (e.g. Cao and Baldwin 1999; Nepal and Somers 1992; Pienaar and Harrison 1988), and the "limitless" diameter class model of Clutter and Jones (1980). Thus, it falls between classically-defined classes of models and incorporates an intermediate structure as discussed by Goelz [in press].

LITERATURE CITED

Boyer, W.D. 1990. *Pinus palustris* Mill. Longleaf Pine. In: R.M. Burns and B.H. Honkala, coord., Silvics of North America. Vol. 1, Conifers. USDA Forest Service, Agric. Handb. 654. Washington, DC. 405-412.

Cao, Q.V.; V.C. Baldwin, Jr. 1999. A new algorithm for stand table projection models. Forest Science. 45: 506-511.

Clutter, J.L.; E.P. Jones, Jr. 1980. Prediction of growth after thinning of old-field slash pine plantations. USDA Forest Service, Research Paper SE-217. Southeast Forest Experiment Station. Ashville, NC. 19 p.

Franklin, R.M. 1997. Stewardship of Longleaf Pine Forests: A Guide for Landowners. Longleaf Alliance Rept. No. 2. The Longleaf Alliance, Solon Dixon Forestry Education Center, Andalusia, AL. 44 p.

Goelz, J.C.G. [in press]. Growth and yield models viewed from a diameter distribution perspective. Journal of Mathematical Modelling and Scientific Computing.

Goelz, J.C.G.; D.J. Leduc. [in press]. Long-term studies on development of longleaf pine plantations. In J.L. Kush, ed., Proceedings of the Third Longleaf Alliance Regional Conference. Forest for Our Future. 16-18 October 2000, Alexandria, LA. The Longleaf Alliance and Auburn University, Auburn University, AL.

Leduc, D.J.; T.G. Matney; K.L. Belli; V.C. Baldwin, Jr. Predicting diameter distributions of longleaf pine plantations: A comparison between artificial neural networks and other accepted methodologies. USDA Forest Service, Research Paper SRS-25. Southern Research Station. Asheville, NC. 18p.

Lohrey, R.E.; R.L. Bailey. 1977. Yield tables and stand structure for unthinned longleaf pine plantations in Louisiana and Texas. USDA Forest Service, Research Paper SO-133. Southern Forest Experiment Station, New Orleans, LA. 53 p.

Nepal, S.K.; G.L. Somers. 1992. A generalized approach to stand table projection. Forest Science. 38: 120-133.

Pienaar, L.V.; W.M. Harrison. 1988. A stand table projection approach to yield prediction in unthinned even-aged stands. Forest Science. 34: 804-808.

Somers, G.L.; R.M. Farrar, Jr. 1991. Biomathematical growth equations for natural longleaf pine stands. Forest Science. 37: 227-244.

ACCURACY OF EASTERN WHITE PINE SITE INDEX MODELS DEVELOPED IN THE SOUTHERN APPALACHIAN MOUNTAINS

W. Henry McNab[1]

Abstract—Three older, anamorphic eastern white pine (*Pinus strobus* L.) site index models developed in the southern Appalachian Mountains between 1932 and 1962 were evaluated for accuracy and compared with a newer, polymorphic model developed in 1971. Accuracies of the older models were tested with data used in development of the 1971 model, in which actual site index had been determined by stem analysis. The 1971 model could not be evaluated for accuracy because independent data were unavailable. Evaluation statistics included prediction accuracy, bias, variance, mean square error, and tolerance interval. For one of the older models, prediction accuracy within 5 percent of observed site index was 100 percent, and other statistics compared favorably. Based on the premise that a polymorphic model best describes growth of eastern white pine over a range of site qualities, the site index model developed in 1932 performed surprisingly well.

INTRODUCTION

Eastern white pine (*Pinus strobus* L.) has long been recognized as one of the most valuable timber species in the southern Appalachian Mountains. This conifer is widely managed in natural and planted stands because of its desirable growth and yield characteristics, as well as the high value of its products. Site index (SI) —the average total height of the dominant and codominant trees of a stand at a specific standard age (Chapman and Myer 1949)— typically is used to measure the relative productivity of this species (Beck 1971). Site index relationships have been developed using various techniques, initially based on purely graphical methods and more recently based entirely on mathematical techniques (Chapman and Myer 1949). All types of SI relationships will be referred to as models in this paper.

Barrett first developed an SI model for eastern white pine (hereinafter white pine) in the southern Appalachian Mountains in 1932. Other models were developed as methods changed for quantifying the relationships that describe tree height increment over time. Five models based on data from the southern Appalachian Mountains are now available for white pine. The most recent model was developed by Beck (1971).

Potential problems associated with developing SI models are well known (Beck 1971, Beck and Trousdell 1973). Most problems are related to the inclusion of data from unrepresentative stands and inadequate methods of data analysis (Beck 1971). Each new SI study undoubtedly has reflected investigator intent to overcome perceived problems with earlier models. Therefore, a logical question might be: "Have white pine SI models evolved from less accuracy to greater accuracy over the past 70 years?" None of the southern Appalachian models has been tested for accuracy. This paper evaluates the accuracy of white pine SI models developed in the southern Appalachians.

METHODS

Site Index Models

I examined the performance of four SI models that use a standard age of 50 years:

1. Barrett (1932) developed the first set of SI curves from "...measurements of 376 dominant and codominant trees growing in mixture with hardwoods..." He did not state his method for development of these curves, but likely based it on the guide-curve technique, where the age and height of individual trees throughout a region are measured, and one must assume that the population of site indices has been sampled adequately across all stand ages. The resulting SI model is derived from a single guide-curve that describes the average height increment relationship for the total set of sampled stands (Chapman and Meyer 1949). Site index models of this type are termed anamorphic because one curve shape describes the height-growth relationship over the entire range of site qualities sampled.

2. Doolittle and Vimmerstedt (1960) supplemented Barrett's data with additional observations from 105 plots in natural stands of pure white pine and mixed species composition in northern Georgia and western North Carolina. They, too, used the guide-curve method. However, recognizing that the rate of height growth varied with site quality, they attempted to correct for that effect using a mathematical technique based on the coefficient of variation (Chapman and Meyer 1949).

3. Vimmerstedt (1959, 1962) sampled 78 planted stands in North Carolina, Tennessee, and Georgia and established 111 plots for preparation of an SI model. Using linear regression, they developed an equation for predicting tree height at 25 years as a function of height and age, but they did not present statistics describing fit of the model. Vimmerstedt (1962) presented a conversion factor for

[1]Research Forester, Bent Creek Experimental Forest, 1577 Brevard Road, Asheville, NC 28806.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

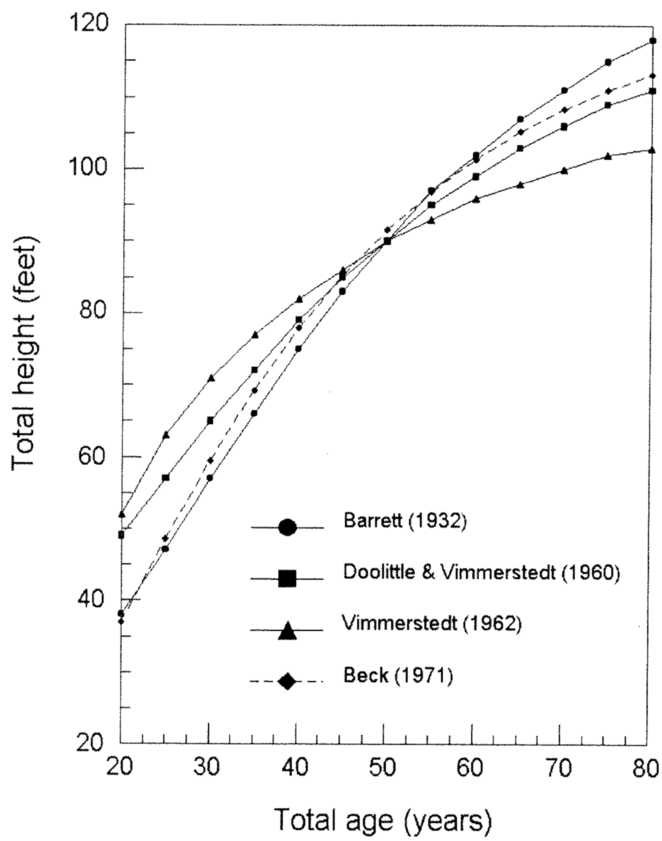


Figure 1—Comparison of eastern white pine site index curves developed in the southern Appalachian Mountains for site index 90 feet.

changing SI at a standard age of 25 to a standard age of 50 years.

4. Beck (1971) sampled 43[1] even-aged stands of naturally established white pine in western North Carolina, northern Georgia, eastern Tennessee, and southwestern Virginia. He used stem-analysis methods to determine the total height of each sample tree at successive ages, up to and including 50 years, which provided a direct measurement of observed SI for that site. He used a non-linear sigmoid function to derive a set of polymorphic curves whose shape varied in relation to site quality.

Summarized in table 1 are characteristics and ranges of total stand ages and site indices over which each of the four SI relationships can be applied. Predicted stand height over age for each of the models is presented in figure 1 for a SI of 90.

Independent Data Set

I used field data collected by Beck (1971) as an independent data set for evaluating each of the SI models. The SI of Becks (1971) 43 stands averaged 92.7 feet (range 69 - 122), ages averaged 52.5 years (43 - 71), and total heights averaged 95.1 feet (70 - 119). About a quarter of the stands were 48-years-old or less, a quarter were 49 - 51 years, and about half of the stands were 52-years or older (table 2). Additional information on field methods is described by Beck (1971). A deficiency of this independent data set is that it is not a random sample of the population of all site indices, but Beck (1971) selected it to represent certain conditions necessary for development of his model (Beck and Trousdell 1973).

I used each of the four models to predict SI of the 43 stands. I predicted SI to the nearest foot by reading directly from published age and height graphs for the models developed by Barrett (1932), and Doolittle and Vimmerstedt (1960). I obtained predicted SI by solving equations presented by Vimmerstedt (1962) and Beck (1971). However, because independent data were used in development of Beck's SI model, this data set cannot be used to validate his model. Performance results for the model developed by Beck (1971) are presented as a standard for comparison with the other models. The most recently developed SI model (Beck 1971) is referred to as the standard model; the other three are, collectively, the old models.

Model Performance Criteria

SI model performance is associated with and implies an unspecified accuracy of prediction. Accuracy is measured in terms of: bias and precision. Bias of a model is the average difference between predicted and the observed values. Precision is a measure of the scatter of predicted SI values around their mean value. Thus, an SI model may be characterized as: (1) unbiased and precise, (2) unbiased but imprecise, (3) biased but precise, or (4) biased and imprecise. An accurate model should have attributes of being both unbiased and precise. In some instances a model could have varying degrees of bias or imprecision

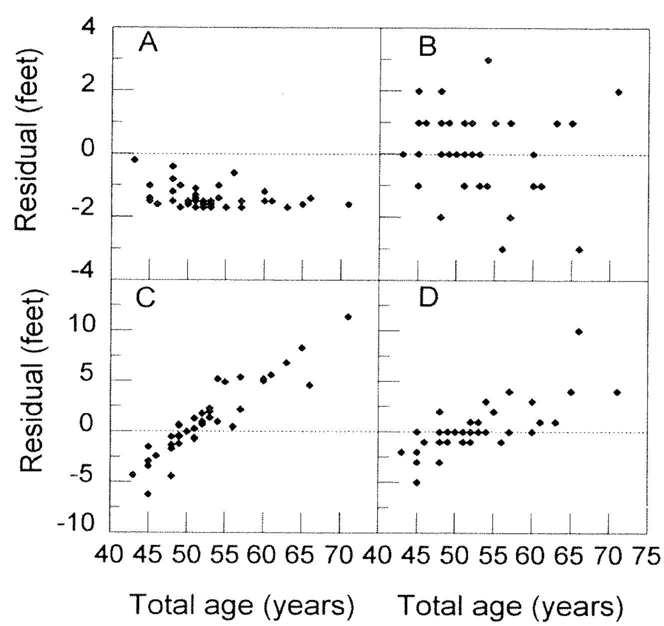


Figure 2—Residuals (predicted - observed) of eastern white pine site index resulting from application of a model used as a standard of comparison (A: Beck 1971) and three models evaluated for accuracy with an independent data set (B: Barrett, 1932; C: Vimmerstedt 1962; D: Doolittle and Vimmerstedt 1960).

[1]Beck (1971) used only 42 of the 43 stands sampled to develop his SI model. The identity of and reason for excluding one stand is unknown.

Table 1—Site index models for eastern white pine developed in the southern Appalachian Mountains

Model source	Stand type	Model format	Standard age (yrs)	Model ranges of Age (yrs)	Model ranges of SI (ft)
Barrett (1932)	Natural	Graph	50	20-120	50-130
Beck (1971)	Natural	Equation	50	5- 70	60-130
Doolittle and Vimmerstedt (1960)	Natural	Graph	50	20-100	50-130
Vimmerstedt (1959)	Planted	Equation	25	10- 35	40- 80
Vimmerstedt (1962)	Planted	Equation	50	10- 59	57-115

and still have acceptable accuracy. Each condition presents a different set of implications associated with model accuracy.

I evaluated the performance of each model using a number of statistics associated with accuracy. Because I was interested in learning the difference between observed and predicted SI values, I first determined the residual of each observation (stand):

$$\text{Residual} = (\hat{Y}_i - Y_i)$$

where $\hat{Y}_i$ is the predicted SI for a stand, and Y_i is the observed SI value for the same stand. For many statistical comparisons, the standard method of calculating residuals is $(Y_i - \hat{Y}_i)$. However, I and others (Wiant 1993, Rauscher and others 2000) have used the reverse formulation because it provides results that are more easily comprehended: model overpredictions are positive errors and underpredictions are negative errors.

Bias is the mean of the residuals for all stands:

$$\text{Bias} = \Sigma\,(\text{Residual}_i)/n$$

where n is the number of sampled stands (here, 43).

The scatter of the residuals around the mean of observed SI for a model is a measure of its precision, which is quantified by the variance:

$$\text{Variance} = \Sigma\,(\overline{Y}-Y_i)^2/n\text{-}1$$

where $\overline{Y}$ is the mean of all observed SI.

The bias and variance can be combined into single statistic, the mean square error:

$$\text{MSE} = \text{bias}^2 + \text{variance}$$

which provides a measure of the model accuracy and is an indication of the model that performs best overall for estimation of SI. A disadvantage of MSE is that it cannot be used to compare relative performance of models from other studies because it is dependent on the number of observations.

Two other statistics were used to overcome the limitations of MSE and provide a more easily understood measure of future prediction errors: prediction accuracy and tolerance interval. Rauscher and others (2000) used prediction accuracy (PA) to provide a measure of the proportion of predictions that occurred within a specified distance of the observed value. I used a PA value of ±5 percent (e.g. PA-5), which is about equivalent to estimates within one SI class

Table 2—Number of stands by total age and observed site index classes in the independent data set sampled by Beck (1971)

Age[a] (yrs)	Site index (ft) 70	75	80	85	90	95	100	105	110	115	120	Total
45				1	1	1	1		1		1	6
50	1	1	3	3	4	1	3	2	2		1	21
55			2	1	1	3			1	1		9
60					2			1				3
65	1	1					1					3
70		1										1
Total	2	3	5	5	8	5	5	3	4	1	2	43

[a]Midpoints of age and site index classes (e.g., 45 = 43 through 47, 70 = 68 through 72).

Table 3—Error analysis statistics for three site index models developed for eastern white pine in the southern Appalachian Mountains compared to a model developed by Beck (1971) that was used as a standard of comparison

Category of site index model and source of model	Statistic PA-5[a] (pct)	Bias (ft)	Variance (ft)	MSE[b] (ft)	TI[c] (ft)
Site index models tested					
Barrett (1932)	100	0.17	1.56	1.59	3.03
Doolittle and Vimmerstedt (1960)	93	0.14	5.86	5.89	5.86
Vimmerstedt (1962)	77	1.14	12.22	13.53	8.47
Site index standard					
Beck (1971)	100	-1.47[d]	0.13	2.30	0.89

[a]Precision accuracy = Percent of predicted site index values within 5 pct of actual.
[b]Mean square error = Bias^2 + variance.
[c]Tolerance interval = Bias ± limits of SI that will include 95 pct of future errors 95 pct of the time.
[d]Significantly different from zero at the 0.05 level of probability.

of 10 feet. Reynolds (1984) suggested calculation of tolerance interval as a means of determining the limits within which most errors will occur in an SI model. The tolerance interval is equal to the mean bias plus or minus the limits of predicted SI that will include 95 percent of future errors at a 0.95 level of probability. I calculated all statistics (except PA-5) using the computer program DOSATEST, which was developed by Rauscher (1986) and refined by Wiant (1993). DOSATEST calculates a trimmed mean and jackknife standard deviation for appropriate tolerance intervals if errors are not normally distributed (Wiant 1993). Accuracy testing using these five statistics (bias, precision, MSE, prediction accuracy, and tolerance interval) and the DOSATEST software has been reported by Wiant (1993) and Rauscher and others (2000).

RESULTS AND DISCUSSION

The PA-5 statistic was highest (100 percent) for two models, Barrett (1932) and the standard (table 3), indicating that all predicted values of SI were within 5 percent of observed. Only 77 percent of stand SI values predicted by the Vimmerstedt (1962) model were within these limits. The pattern of residuals of predicted and observed SI differed for each model (figure 2).

None of the three old SI equations was significantly biased (table 3). However, the equation developed by Beck (1971) exhibited a bias of -1.47 feet (see panel A in figure 2), which was significantly different from zero at the 0.05 level of probability. For example, on a plot with tree height 90 feet at 50 years, the standard model predicts SI as about 88.5 feet. The observed bias results from the model not being constrained, or adjusted, to pass through a value of SI equal to stand height at 50 years standard age (Personal communication T.Lloyd, Research Forester, USDA Forest Service, 1577 Brevard Road, Asheville, NC 28806), as is generally customary in most SI models. Constraining the model was not addressed by Beck (1971), but likely was not done in order to provide a model of greater overall accuracy. In contrast, Trousdell and others (1974) used a similar model formulation to develop SI curves for loblloly pine (*Pinus taeda* L.) and adjusted the curves to pass through the indicated SI at age 50.

The tolerance interval was least for the standard model, which suggests a high degree of accuracy that is associated with small errors of prediction. Among the old models, tolerance interval was smallest (3.03 feet) for Barrett's (1932) and greatest (8.47 feet) for Vimmerstedt's (1962). For Barrett's model, which has a bias of zero (i.e. mean bias was 0.17, which was not significantly different from zero), the tolerance interval may be interpreted to indicate a 95 percent confidence that at least 95 percent of the population of future errors will occur within an interval of about ±3 feet of actual SI.

Mean square error, which combines the effects of bias and variance, was least for Barrett's model. The relatively large bias of the standard model (-1.47 feet) contributed to its large MSE. In many situations, however, a model with a large bias and small variance (e.g., Beck 1971) is preferable to a model with a small bias and large variance (e.g., Barrett, 1932). This is because prediction errors associated with bias can be easily corrected, but accounting for error arising from imprecision is problematic.

An explanation for the relatively poor performance of the Vimmerstedt (1962) model is likely due to several causes. First, unlike the other SI models evaluated, this one was developed in planted stands of white pine but tested using data from natural stands. Effects of stand establishment-method and species composition on SI relationships for white pine are not well known, although planted seedlings typically exhibit greater height growth than natural seedlings until about 5 years (Personal communication, Brian Ritter, Forestry Supervisor, Biltmore Estate, One North Pack Square, Asheville, NC 28801). Second, over 80 percent of sample trees used in development of the Vimmerstedt model were less than 25 years of age, which tended to weight the curves away from height patterns at a standard age 50 years. Last, Vimmerstedt (1962) presented without explanation a single factor for converting SI at base age 25 to base age 50. Application of the single factor suggests that total height at age 50 would be 1.4335 times that measured at age 25 on all sites. It seems likely that use of a single conversion factor would reduce accuracy of SI models at higher and lower site qualities. In comparison, Trousdell and others (1974) found that height of loblolly pine at 50 years ranged from about 1.4 to 1.7 times that at age 25, depending on site quality. The combination of these and other unknown factors likely contributed to reduced performance of the Vimmerstedt (1962) model.

The tests I conducted were restricted to stand ages 43 - 71 years, which covered only about half the age ranges applicable for most of the models. Tests of the models at younger ages were not possible due to lack of independent data. However, performance of the SI models for younger stand ages may be implied by their performance at the older ages. Assuming that the standard model offers the best representation of height for white pine at all ages, the model developed by Barrett (1932) probably would perform well in younger stands.

CONCLUSIONS

This study has shown that accuracy of eastern white pine SI models varies in the southern Appalachian Mountains. None of the three tested SI models exhibited performance superior to the most recently developed polymorphic model (Beck 1971), which, however, could not be evaluated because a satisfactory data set was not available. One of the anamorphic models (Barrett 1932) compared favorably to the standard model, and several components of its accuracy (bias and MSE) were slightly superior to the standard. The data presented in table 3 are statistics of fit for Beck's (1971) model, rather than independent tests of accuracy.

Results of this study should be useful to researchers for designing new studies and in helping managers decide which SI model to use. One reason I made this study was recognition of how little information is in the literature on the topic of SI validation testing. Site index models are one of the most commonly used forms of prediction equations in forestry; they typically are developed, presented, and used with no accompanying evaluation of performance. The DOSATEST program provides an easy-to-use tool for making tests of accuracy. The primary conclusions are that plantation SI curves seem to differ from natural stands, and that curves developed at two different times for the same region using very different model developmental techniques produced very similar results.

ACKNOWLEDGMENTS

I thank H. Michael Rauscher for providing the DOSATEST software. I also thank F. Thomas Lloyd and Mike Rauscher for many discussions on the topic of accuracy tests in forest measurements that led me to make this study. Tom Lloyd and Brian Ritter reviewed an early draft of this paper. Their suggestions for improvements are greatly appreciated.

LITERATURE CITED

Barrett, L.I. 1932. Second growth white pine height growth classification. Tech. Notes 5. U.S. Department of Agriculture, Forest Service, Appalachian Forest Experiment Station. 1 p.

Beck, D.E. 1971. Polymorphic site index curves for white pine in the Southern Appalachians. Res. Pap. SE–80. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 8 p.

Beck, D.E.; Trousdell, K.B. 1973. Site index: accuracy of prediction. Res. Pap. SE–108. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 7 p.

Chapman, H.H.; Meyer, W.H. 1949. Forest mensuration. New York: McGraw-Hill Book Co. 522 p.

Doolittle, W.T.; Vimmerstedt, J.P. 1960. Site index curves for natural stands of white pine in the Southern Appalachians. Res. Note 141. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 2 p.

Rauscher, H.M. 1986. The microcomputer scientific software series 4: testing prediction accuracy. Gen. Tech. Rep. NC–107. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 19 p.

Rauscher, H.M.; Young, M.J.; Webb, C.D.; Robison, D.J. 2000. Testing the accuracy of growth and yield models for southern hardwood forests. Southern Journal of Applied Forestry. 24: 176–185.

Reynolds, M.R. 1984. Estimating the error in model predictions. Forest Science. 30: 454–469.

Trousdell, K.B.; Beck, D.E.; Lloyd, F.T. 1974. Site index for loblolly pine in the Atlantic Coastal Plain of the Carolinas and Virginia. Res. Pap. SE–115. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 11 p.

Vimmerstedt, J.P. 1959. Site index curves for Southern Appalachian white pine plantations. Res. Note 131. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 2 p.

Vimmerstedt, J.P. 1962. Southern Appalachian white pine plantations: site, volume, and yield. Stn. Pap. 149. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 13 p.

Wiant, H.V., Jr. 1993. DOSATEST for testing accuracy. Compiler. 11: 28–29.

NONLINEAR PROGRAMMING MODELS TO OPTIMIZE UNEVEN-AGED SHORTLEAF PINE MANAGEMENT

Benedict J. Schulte and Joseph Buongiorno[1]

Abstract—Nonlinear programming models of uneven-aged shortleaf pine (Pinus echinata Mill.) management were developed to identify sustainable management regimes that optimize soil expectation value (SEV) or annual sawtimber yields. The models recognize three species groups (shortleaf pine and other softwoods, soft hardwoods and hard hardwoods) and 13 2-inch diameter-at-breast-height size classes. Reproduction, growth and mortality rates are a function of tree diameter, stand density and site productivity. The optimal economic and production regimes each involve a guiding maximum diameter for softwoods and periodic hardwood control, with the optimal maximum diameter a function of site productivity.

INTRODUCTION

Growing public demand for non-commodity forest values such as biological diversity, scenic beauty, recreational opportunities and wildlife habitat has lead to increased interest in uneven-aged management. Yet models to predict the effects of specific management regimes on stand structure, species composition, timber production, economic returns and sustainability are not readily available for many forest types. This remains true for shortleaf pine, despite its economic importance and wide distribution. To help address this situation, we developed mathematical programming models to identify sustainable management regimes that maximize economic returns or annual sawtimber production for uneven-aged shortleaf pine.

GROWTH MODEL

To estimate stand growth, a site- and density-dependent matrix transition model was developed using data from 1047 naturally regenerated, shortleaf pine re-measurement plots of the Southern Forest Inventory and Analysis (FIA) database (table 1, Hansen and others 1992). The average interval between inventories was 8.6 years. Observed upgrowth and mortality probabilities and ingrowth rates were converted to a one-year interval by exponential interpolation.

The model's structure follows Lin and others (1998). Trees are categorized into thirteen 2-inch diameter-at-breast height (DBH) size classes and three species groups: shortleaf pine and other softwoods, soft hardwoods and hard hardwoods. Size classes are denoted by their midpoint diameters and range from size class 2 to size class 26+, which contains all trees 25 inches DBH and larger. The model was calibrated on 838 plots (80 percent) chosen randomly from the 1047 available. The remaining 209 plots were used to test the accuracy of the model prior to re-estimating the parameters using data from all 1047 plots.

Table 1—Distribution of sample plots by state and inventory[a]

Inventory						*State*							
Year	AL	AL	AR	AR	LA	LA	MS	MS	OK	OK	TN	TX	TX
Current	'82	'90	'88	'95	'84	'91	'87	'94	'86	'93	'89	'86	'92
Previous	'72	'82	'78	'88	'74	'84	'77	'87	'76	'86	'80	'75	'86
Plots	108	47	192	174	34	21	85	42	82	85	14	85	78

[a]Inventories may span more than one year.

[1]Research Assistant, Professor, Department of Forest Ecology and Management, 1630 Linden Drive, Madison, WI 53706-1598, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 2—Equations for annual ingrowth (trees/ac/yr)[a]

Sp.[b]	Stand BA (ft^2/ac)	Site (ft^3/ac /yr)	Species BA (ft^2/ac)	Con-stant	R^2	dF
SW	-0.597 **		0.41 **	41.9 **	0.12	1044
SH	-0.077 **	0.058 **	0.41 **	6.9 **	0.14	1043
HH	-0.091 **	0.059 *	0.13 *	12.7 **	0.02	1043

[a]Asterisks denote level of significance: *, 0.01; **, 0.0001.
[b]Species groups: SW, shortleaf pine and other softwoods; SH, soft hardwoods; HH, hard hardwoods.

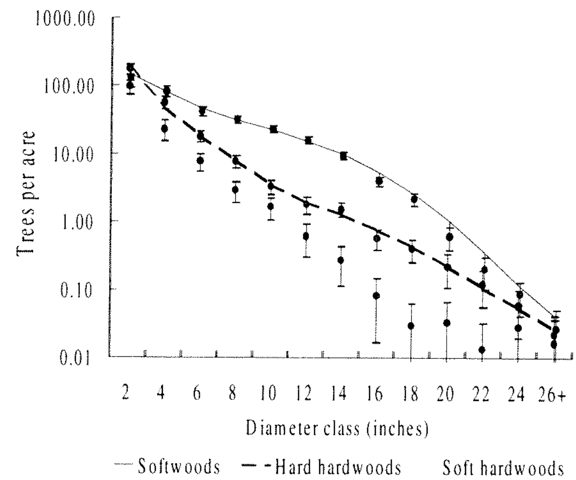


Figure 1—Average observed (dots, with 95 percent confidence intervals) and predicted (lines) distributions of shortleaf pine and other softwood, soft hardwood and hard hardwood trees on 209 post-sample plots after an average 8.6-years growth.

Ingrowth Rates

Table 2 gives the parameter estimates for the final ingrowth equations. Ingrowth rates were inversely proportional to total stand basal area and directly proportional to the basal area of the given species group, presumably reflecting the presence of more seed-producing trees. Site productivity had a significant, positive effect on the ingrowth of the soft hardwoods and hard hardwoods but not the shortleaf pine and other softwoods.

Upgrowth Probabilities

The upgrowth probability equations' parameters are in table 3. As expected, upgrowth probabilities were inversely proportional to stand density, directly proportional to site productivity, and a quadratic function of tree diameter for all three species groups. Upgrowth probabilities were lowest at small diameters, peaked at intermediate diameters, and declined again at large diameters.

Mortality Probabilities

The parameter estimates for the mortality equations are in table 4. All three species groups exhibit the expected convex relationship between diameter and mortality. Mortality probabilities were highest at small diameters, reached their lowest levels at intermediate diameters, and increased again at large diameters. For the shortleaf pine and other softwoods group, mortality probabilities were also significantly higher at higher stand densities and on more productive sites.

Projection Accuracy

To test the accuracy of the growth model for projections as long as the interval between two FIA inventories, the initial model, developed with data from the 838 estimation plots, was used to predict the diameter frequency distributions of the 209 validation plots at the current inventory given their distribution at the previous inventory and any intervening harvest. Figure 1 shows how the predicted distributions compared with the observed distributions. For most species-diameter categories, the average of the predicted number of trees was within the 95 percent confidence interval of average observed number of trees, though there was a slight tendency for the model to over predict the number of large shortleaf pine and other softwood trees.

YIELD MODEL

Cubic-foot sawlog and pulpwood volumes of individual trees are estimated using equations fitted to the stem

Table 3—Equations for probability of transition between size classes in 1 year[a]

DF Sp.[b]	Stand BA (ft^2/ac)	Site (ft^3/ac/yr)	DBH (in.)	DBH^2 ($in.^2$)	Constant	R^2	DF
SW	-0.00034 **	0.00021 **	0.01000 **	0.00034 **	0.02740 **	0.09	5702
SH	-0.00018 *	0.00020 **	0.00830 **	-0.00032 **	0.00170	0.08	1234
HH	-0.00020 **	0.00022 **	0.00750 **	-0.00022 **	0.00470	0.10	2854

[a]Asterisks denote level of significance: *, 0.01; **, 0.0001.
[b]Species groups: SW, shortleaf pine and other softwoods; SH, soft hardwoods; HH, hard hardwoods.

Table 4—Equations for probability of mortality in 1 year[a]

Sp.[b]	Stand BA (ft^2/ac)	Site (ft^3/ac /yr)	DBH (in.)	DBH^2 (in.^{2})	DBH^{-1} (1/in.)	Constant	R^2	dF
SW	0.0000560 **	0.00014 ***		0.000014 *	0.158 ***	-0.028 ***	0.22	5728
SH			-0.00470 ***	0.000160 ***		0.0360 ***	0.04	1244
HH			0.00085 **		0.092 ***	-0.007 ***	0.07	2878

[a]Asterisks denote level of significance: *, 0.01; **, 0.001; ***, 0.0001.
[b]Species groups: SW, shortleaf pine and other softwoods; SH, soft hardwoods; HH, hard hardwoods.

Table 5—Equations for sawlog volume (cubic feet)[a]

Sp.[b]	DBH^2 (in.^{2})	Sawlog (ft)	Constant	R^2	dF
SW	0.13	1.02	-36.1	0.94	299
SH	0.11	1.13	-23.6	0.96	229
HH	0.10	1.12	-31.6	0.96	225

[a]Fitted to the stem volume equations of Clark and Souter (1994). All coefficients are significant at the 0.0001 level.
[b]Species groups: SW, shortleaf pine and other softwoods; SH, soft hardwoods; HH, hard hardwoods.

Table 6—Equations for pulpwood volume per tree (cubic feet)[a]

Sp.[b]	Height (ft)	DBH^2 (in.^{2})	Constant	R^2	dF
SW	0.12	0.13	-36.1	0.97	47
SH	0.11	0.11	-23.6	0.97	80
HH	0.11	0.10	-31.6	0.97	80

[a]Fitted to the stem volume equations of Clark and Souter (1994). All coefficients are significant at the 0.0001 level.
[b]Species groups: SW, shortleaf pine and other softwoods; SH, soft hardwoods; HH, hard hardwoods.

Table 7—Equations for top pulpwood volume per tree (cubic feet)[a]

Sp.[b]	Height (ft)	Sawolg (ft)	DBH^2 (in.^{2})	Constant	R^2	dF
SW	0.067	-0.99	0.067	-21.5	0.89	298
SH	0.057	-1.06	0.057	-22.3	0.91	228
HH	0.056	-1.07	0.056	-17.0	0.91	224

[a]Fitted to the stem volume equations of Clark and Souter (1994). All coefficients are significant at the 0.0001 level.
[b]Species groups: SW, shortleaf pine and other softwoods; SH, soft hardwoods; HH, hard hardwoods.

Table 8—Equations for total tree height (feet)[a]

Sp.[b]	Stand BA (ft^2/ac)	Site (ft^3/ac /yr)	Site^2 (ft^6/ac^2 /yr^2)	DBH (in.)	DBH^{-1} (1/in.)	Constant	R^2	dF
SW	0.090	0.42	-0.0010	1.04	-182	30.9	0.66	17815
SH	0.057	0.39	-0.0013		-274	56.4	0.55	1216
HH	0.071	0.44	-0.0013	0.75	-143	24.3	0.52	3654

[a]All coefficients are significant at the 0.0001 level.
[b]Species groups: SW, shortleaf pine and other softwoods; SH, soft hardwoods; HH, hard hardwoods.

Table 9—Equations for sawlog length (feet)[a]

Sp.[b]	Height (ft)	DBH (in.)	DBH^{-1} (1/in.)	Constant	R^2	dF
SW	0.83	-2.2	-396	-36.1	0.75	11901
SH	0.49		-234	-32.6	0.44	291
HH	0.38	-1.9	-465	-31.6	0.37	1349

[a]All coefficients are significant at the 0.0001 level.
[b]Species groups: SW, shortleaf pine and other softwoods; SH, soft hardwoods; HH, hard hardwoods.

Table 10—Stumpage prices[a]

	Species group Pulpwood ($/cord)	Species group Sawtimber ($/Mbf)
Softwoods	21.88	324[b]
Soft hardwoods	13.85	153[c]
Hard hardwoods	13.85	291[c]

[a]Source: Timber Mart-South (Sept. 1999 – Aug. 2000).
[b]Scribner log rule; [c]Doyle log rule.

Table 11—Steady-state management regimes that maximize soil expectation value on low, medium and high productivity sites[a]. Trees harvested each cutting cycle are denoted by asterisks

	--Low site--			-Medium site-			--High site--		
Size	SW	SH	HH	SW	SH	HH	SW	SH	HH
2	269.5	22.8*	46.6*	239.2	34.8*	58.0*	218.5	73.5*	101.5*
4	112.9	0.4*	1.9*	110.1	2.0*	3.6*	113.8	9.4*	14.3*
6	72.7	0.0*	0.1*	71.2	0.1*	0.2*	76.1	1.0*	1.7*
8	56.8			54.3			58.0	0.1*	0.2*
10	49.4			45.6			31.4*		0.0*
12	18.6*			18.5			11.3*		
14	3.7*			4.1			2.8*		
16	0.4*			0.5*			0.5*		
18	0.0*			0.0*			0.1*		
20									
22									
24									
26+									
Statistics[b]									
Cycle	8			6			9		
SEV	2093			2711			3430		
Saw	81			109			119		
H'_{tree}	41			41			35		

[a]Low site, shortleaf pine site index 67 feet at age 50; medium site, 102 feet; high site, 142 feet.
[b]Cycle, optimal cutting cycle (years); SEV, soil expectation value ($/acre); Saw, annual sawtimber production (ft³/acre/year); H'_{tree}, percent of theoretical maximum tree diversity (pct), after harvest.

Table 12—Steady-state management regimes that maximize annual sawtimber production on low, medium and high productivity sites[a]. Trees harvested each cutting cycle are denoted by asterisks

	Low site			Medium site			High site		
Size	SW	SH	HH	SW	SH	HH	SW	SH	HH
2	251.5	20.0*	46.3*	234.9	5.7*	10.4*	223.7	18.2	27.7*
4	94.9	0.8*	1.9*	101.5			111.3	0.3	0.5*
6	58.3	0.0*	0.1*	63.5			72.6		
8	44.2			47.8			54.6		
10	37.7			39.3			44.6		
12	34.7			34.7			8.2*		
14	14.8*			3.0*			0.4*		
16	3.4*								
18	0.5*								
20	0.0*								
22									
24									
26+									
Statistic[b]									
Cycle	7			1			2		
SEV	1595			486			2968		
Saw	88			111			133		
H'_{tree}	45			46			41		

[a]Low site, shortleaf pine site index 67 feet at age 50; medium site, 102 feet; high site, 142 feet.
[b]Cycle, optimal cutting cycle (years); SEV, soil expectation value ($/acre); Saw, annual sawtimber production (ft³/acre/year); H'_{tree}, percent of theoretical maximum tree diversity (pct), after harvest.

volume tables of Clark and Souter (1994). Pulpwood is potentially available from poletimber trees (softwoods 5 to less than 9 inches DBH or hardwoods 5 to less than 11 inches DBH) and from the tops of sawtimber trees (softwoods 9 inches DBH and larger or hardwoods 11 inches DBH and larger). Pulpwood volumes of poletimber trees (table 5) are a linear function of tree height and diameter squared; whereas pulpwood volumes from the tops of sawtimber trees (table 6) are a linear function of tree height, sawlog length and diameter squared. Sawlog volumes (table 7) are a linear function of sawlog length and diameter squared.

Total heights of the average tree in each size class of a particular species group are estimated using equations based on more than 22,000 trees on the 1047 plots used to develop the growth model. Table 8 gives the empirical tree height equations. For a given size class, trees were taller in stands with more basal area and on more productive sites. Similarly, sawlog lengths are estimated using equations based on more than 13,000 trees from the same plots. The empirical sawlog length equations are in table 9. Sawlog length was a function of tree diameter and height.

OPTIMIZATION MODELS

Maximizing Soil Expectation Value

Knowing the maximum economic return that can be obtained from a particular site provides a useful measure for comparing the economic performance of alternative management regimes. The preferred measure of a management regime's economic performance, when applied to a stand of a given productivity, is the soil expectation value (SEV), the present value of all future harvests, net of all costs, including the opportunity cost of the growing

[1]The optimization models presented in this paper have non-concave response surfaces, thereby necessitating the use of nonlinear programming techniques. Consequently, the optimal regimes they identify are locally, though not necessarily globally, optimal. To improve the likelihood of finding globally optimal solutions, each problem was solved 50 times, each time beginning with different initial values.

stock. Because SEV is highly influenced by a stand's initial structure and to ensure sustainability, only steady-state management regimes, those in which the stand returns to the same pre-harvest diameter distribution each cutting cycle, are considered here. Consequently, the model[1] to identify the sustainable, uneven-aged management regime that maximizes soil expectation value is:

$$\max_{\mathbf{y}_0,\mathbf{h}_0} SEV = \frac{\mathbf{s}'\mathbf{h}_0 - F}{(1+r)^C - 1} - \mathbf{s}'(\mathbf{y}_0 - \mathbf{h}_0) \quad (1)$$

subject to:

$$\mathbf{y}_1 = \mathbf{G}_0(\mathbf{y}_0 - \mathbf{h}_0) + \mathbf{I}_0$$
$$\mathbf{y}_2 = \mathbf{G}_1(\mathbf{y}_1) + \mathbf{I}_1$$
$$\mathbf{y}_C = \mathbf{G}_{C-1}(\mathbf{y}_{C-1}) + \mathbf{I}_{C-1} \quad (2)$$
$$\mathbf{y}_C = \mathbf{y}_0 \quad (3)$$
$$\mathbf{y}_0 - \mathbf{h}_0 \geq \mathbf{0} \quad (4)$$
$$\mathbf{h}_0 \geq \mathbf{0} \quad (5)$$

where C is the cutting cycle, $\mathbf{y}_t$ is a vector containing the number of trees per acre of species group i and size class j at the start of year t, $\mathbf{h}_0$ is a vector containing the number of live trees per acre of species group i and size class j harvested each cutting cycle, $\mathbf{G}_t$ is a matrix containing transition probabilities for year t, and $\mathbf{I}_t$ is a vector containing the ingrowth for year t (i.e., the number of trees entering the smallest size class of each species).

The stumpage values of individual trees, s, are obtained by multiplying their pulpwood (cords) and sawtimber (board-feet) volumes by their stumpage prices. The stumpage prices used in this analysis are 1999-2000 average prices, weighted by area, for the Southeastern United States (table 10, Timber Mart-South). Pulpwood cubic-foot volumes are converted to cords assuming 72 cubic feet per cord for softwoods and 79 cubic feet for hardwoods. Koch's conversion table (Koch 1972) is used to convert cubic-foot sawlog volumes to board-foot measures (Scribner log rule for softwoods and Doyle log rule for hardwoods). Costs not already reflected in the stumpage prices, F, such as administration and hardwood control, are assumed to total \$80.00 per acre, while the real rate of interest, r, is set at 4 percent.

Equations (2) are the growth equations[2]. There is one equation for each year of the cutting cycle. Equation (3) is the steady-state constraint, which ensures sustainability by requiring the stand to return to the same pre-harvest distribution each cutting cycle. Equation (5) guarantees that the number of trees harvested from the stand does not exceed the number of trees present; whereas equations (4) and (5) together ensure that the number of trees in, and harvested from, each species-size category is nonnegative.

Maximizing Annual Sawtimber Production

While economic concerns may be a key concern of many forest landowners and managers, others are likely to be more interested in the volume of sawtimber that can be produced on a sustainable basis. The model to maximize annual sawtimber production is:

$$\max_{\mathbf{y}_0,\mathbf{h}_0} Saw = \frac{\mathbf{v}_s'\mathbf{h}_0}{C} \quad (6)$$

subject to:
(2), (3), (4) and (5)

where $\mathbf{v}_s$ is a vector containing the cubic-foot sawtimber volumes of trees in each species-size category.

Measuring Tree Diversity

In addition to managing for economic returns and timber production, forest landowners are also increasingly interested in managing for biological diversity. Because the distribution of trees by species and size largely determines a stand's structure, and thus the ecological niches available to other organisms, tree diversity is a key component of a stand's overall diversity (Wilson 1974, Rice and others 1984). One of the most widely used and accepted diversity indices is Shannon's index (Pielou 1977, Magurran 1988). Here we define Shannon's index of tree diversity in terms of basal area, rather than number of individuals, to give added weight to larger trees:

$$H_{trees} = -\sum_{i=1}^{m} \frac{b_{ij}}{b+\varepsilon} \ln\left(\frac{b_{ij}+\varepsilon}{b+\varepsilon}\right) \quad (7)$$

where b_{ij} is the residual basal area in species group i and size class j, b is the residual stand basal area and epsilon is a small, positive constant (0.001) used to avoid division by zero and natural logarithm of zero errors. As defined here, Shannon's index reaches its maximum value of 3.66 [ln(39)] when the residual basal area is distributed evenly among each of the thirty-nine species-size categories. It provides a useful measure for comparing the tree diversity of the optimal economic and sawtimber regimes.

RESULTS AND DISCUSSION

Table 11 gives the steady-state management regimes that maximize SEV on low (shortleaf pine site index 67 at age 50 years), medium (site index 102), and high productivity

[2]Because the parameters of the growth and ingrowth matrices are derived from regression equations which contain negative coefficients for residual stand basal area, it is possible for the predicted transition probabilities and ingrowth rates to be negative when the residual basal area is sufficiently high. To avoid such biologically infeasible predictions, the right hand side of each applicable regression equation, call it "z", was replaced by the expression "$[z + (z^2)^{1/2}]/2$. This expression returns the original value of "z" if it is positive and zero otherwise. This equation was also used, as needed, with regression equations for predicting sawtimber and pulpwood volumes.

(site index 142) sites. The optimal cutting cycles are 8, 6 and 11 years, respectively. In all three cases, the hardwoods are completely controlled at each harvest and the shortleaf pines and other softwoods are managed with a guiding maximum diameter of 11 inches DBH on low and medium sites and 9 inches DBH on high sites.

The optimal regimes give SEVs of $2,093, $2,711 and $3,430 per acre, while producing 81, 109 and 119 cubic feet of shortleaf pine and other softwood sawtimber per acre per year, respectively. The small diameters of softwoods and the absence of hardwoods in the residual stands result in relatively low Shannon indices of tree diversity of 41 percent of the theoretical maximum value on low and medium sites and 35 percent on high sites.

Sawtimber Production

Table 12 shows the optimal management regimes for producing sawtimber on low, medium and high productivity sites. The optimal cutting cycles are 7, 1 and 2 years, respectively. As was the case for the SEV-maximizing regimes, the optimal sawtimber regimes each involve complete hardwood control at each harvest and a guiding maximum diameter for shortleaf pine and other softwoods: 13 inches DBH on low sites and medium site and 11 inches DBH on high sites.

These regimes have annual shortleaf pine and other softwood sawtimber production rates of 88, 111 and 133 cubic feet per acre on low, medium and high sites, respectively. By leaving more large diameter softwoods in the residual stand than the SEV-maximizing regimes, Shannon's index of tree diversity improves to 45, 46, and 41 percent of its theoretical maximum on low, medium and high productivity sites, respectively. In contrast, SEV drops to $1595, $486 and $2968 per acre, respectively. This poorer economic performance is due, in part, to the shorter cutting cycles, which cause the fixed costs to be incurred more frequently.

CONCLUSION

Deciding how best to manage forestlands to meet specific objectives requires a clear understanding of what is possible on different sites. The nonlinear programming models presented here help define these limits for uneven-aged shortleaf pine by identifying sustainable steady-state management regimes that maximize either the soil expectation value or the average annual sawtimber production on low, medium and high productivity sites. In addition, the growth model developed for this study allows land managers to explore additional management strategies for meeting their own specific objectives.

Because tree growth, reproduction, and mortality are highly stochastic processes, our ability to model them accurately is limited. Therefore, the optimal regimes presented in this paper should be interpreted as tentative recommendations and not as proven strategies to be adopted unquestioningly. Likewise, simulation results obtained with the growth model should be interpreted as representing the expected average behavior of a number of similar stands, not as predicting the precise behavior of an individual stand.

ACKNOWLEDGEMENT

This work was supported in part by the Wood Utilization for Ecosystem Management Project, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, by the USDA Forest Service, Southern Research Station and by the School of Natural Resources, University of Wisconsin, Madison. We thank Kenneth Skog and Jeff Prestemon for their collaboration.

REFERENCES

Clark, A., III; Souter; R.A. 1994. Stem cubic-foot volume tables for tree species in the South. Res. Pap. SE-290. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Ashville, NC. 85 p.

Hansen, M.H.; Frieswyk, T.; Glover, J.F.; Kelly, J.F. 1992. The eastwide forest inventory database: Users manual. Gen. Tech. Rep. NC-151. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 48 p.

Koch, P. 1972. Utilization of the southern pines. Agricultural Handbook No. 420. Washington, DC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 1,663 p.

Lin, C.-R.; Buongiorno, J.; Prestemon, J.; Skog., K. 1998. Growth model for uneven-aged loblolly pine stands-Simulations and management implications. Res. Pap. FPL-RP-569. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 13 p.

Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton, NJ: Princeton University Press. 179 p.

Pielou, E.C. 1977. Mathematical ecology. Toronto: John Wiley and Sons. 385 p.

Rice, J.; Anderson, B.W.; Ohmart, R.D. 1984. Comparison of the importance of different habitat attributes to avian community organization. Journal of Wildlife Management. 49: 895-911.

Timber Mart-South. Highlands, NC: Timber Marts, Inc.

Wilson, M.F. 1974. Avian community organization and habitat structure. Ecology. 55: 1017-1029.

A COMPATIBLE STEM TAPER-VOLUME-WEIGHT SYSTEM FOR INTENSIVELY MANAGED FAST GROWING LOBLOLLY PINE

Yujia Zhang, Bruce E. Borders, and Robert L. Bailey[1]

Abstract—Geometry-oriented methodology yielded a compatible taper-volume-weight system of models whose parameters were estimated using data from intensively managed loblolly pine (*Pinus taeda* L.) plantations in the lower coastal plain of Georgia. Data analysis showed that fertilization has significantly reduced taper (inside and outside bark) on the upper segment and augmented the stem merchantable volume there, which was modeled using an adjusted form factor. On the other hand, the unit-weights of fertilized trees were not significantly different from unfertilized trees. Finally, our analysis showed no significant impacts of complete vegetation control on taper, volume or weight characteristics.

INTRODUCTION

Geometry-oriented methodology constructs a theoretically sound and physically meaningful framework for taper prediction equation (Ormerod 1973, Forslund 1982, Newberry and others. 1989, Bailey 1994, Byrne and Reed 1986, Broad and Wake 1995, Parresol and Thomas 1996, Fang and Bailey 1999, Fang and others. 2000). The associated merchantable volume equation is mathematically compatible with the total volume equation, that is, it results from integration of the taper function (Demaerschalk 1972, Clutter 1980, Byrne and Reed 1986, McTague and Bailey 1987, Bailey 1994, Fang and Bailey 1999, Fang and others. 2000).

Recently, intensive management has been applied in the Southeastern U.S. (Jokela and Stearns-Smith 1993) to accelerate tree and stand growth and increase financial returns. Many of these silvicultural treatments have been shown to result in dramatic growth increases (Ford 1984, Gent and others. 1986, Allen and others. 1990, Stearns-Smith and others. 1992, Jokela and Stearns-Smith 1993, Borders and Bailey 1997). However, the effect of these treatments on individual tree stem taper, volume, and weight has not been fully studied. Borders and Bailey (1997) reported an extremely fast growth rate of loblolly pine (*Pinus taeda* L.) obtained from intensively managed stands in the Southeastern U.S. The thirteen-year growth of the most responsive stands yielded an average annual increment of 1.50 cm for quadratic mean diameter and 1.55 m for dominant height. Obviously, when such dramatic growth rate differences exist it is possible that stem taper and unit weight may be impacted as well.

STUDY MATERIALS

This investigation used data from the Consortium for Accelerated Pine Plantation Studies (CAPPS) initiated in 1987 and maintained by the Daniel B. Warnell School of Forest Resources, University of Georgia. The treatments employed were: 1)Complete vegetation control throughout stand life-span using herbicide (H), 2)Annual fertilization (F), 3)Herbicide and Fertilization (HF), and 4)Check (C). In the winter of 1999, 192 trees with age 12, 10, and 6 years old were harvested from two study installations from the lower coastal plain of Georgia for wood quality research. Stem taper and weight measurements were made in field and disk analysis was done in the USDA Forest Service laboratory in Athens, GA. The impacts of cultural treatments and age on stem taper were investigated using the split-split plot design. The dependent variables employed are form quotients inside and outside bark at height proportion 0.25, 0.50, 0.60, 0.75, and 0.90, considering that the change of a specified quotient implies the change of stem form, which may be related to cultural treatments. Data analysis showed 1) no significant impacts from treatment H, 2) significant effects of treatment F are found only for quotients of 0.75 and 0.90, and 3) age is not a significant contributor.

MODEL STRUCTURE

Fang and others. (2000) proposed a system of compatible volume-taper models for traditionally managed loblolly pine and slash pine (*Pinus elliottii* Engelm) plantations, in which two inflection points (three segments) were employed. Screening the taper profile of stems in this study (figure 1), one inflection point seems adequate for our taper prediction equations. Followings are derived models for stem taper, volume, and weight.

Taper (Outside Bark)

The derivation of taper equation is similar to the method introduced by Fang and others. (2000) except 1) Newton's segment volume equation was employed in the derivation and 2) a boundary condition that dob = dbh where stem

[1]Research Coordinator, Professor, Retired Facilty, D. B. Warnell School of Forest Resource, The University of Georgia, Athens, GA, USA, repectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

$$dob = dbhH'^{\frac{k-\beta_1}{2\beta_1}} \left(a^{\theta} (1-p)^{\frac{k-\beta_1^{1-\theta}\beta_2^{\theta}}{\beta_1^{1-\theta}\beta_2^{\theta}}} \right)^{\frac{1}{2}} \quad (1)$$

height = breast height.

where *dob* is the stem diameter outside bark, *dbh* the diameter at breast height, $p = \frac{h}{H}$, *h* the stem height, *H* the total height, $H' = \frac{H}{H - 1.3716}$, $k = \frac{\pi}{8}$, $a = (1-p')^{k\frac{\beta_2-\beta_1}{\beta_1\beta_2}}$, *p'* the stem ration at the inflection point, β_1 *and* β_2 the coefficients, and *q* the dummy variable with value zero for stem ratio $p = p'$ and one for $p > p'$,

Taper (Inside Bark)

Taper inside bark (*dib*) is similar to stem taper outside bark, except an extra coefficient *c* because of the effect of tree bark at breast height:

$$dib = c \cdot dbhH'^{\frac{k-\gamma_1}{2\gamma_1}} \left(a'^{\theta} (1-p)^{\frac{k-\gamma_1^{1-\theta}\gamma_2^{\theta}}{\gamma_1^{1-\theta}\gamma_2^{\theta}}} \right)^{\frac{1}{2}} \quad (2)$$

where $a' = (1-p')^{k\frac{\gamma_2-\gamma_1}{\gamma_1\gamma_2}}$, and γ_1 and γ_2 the coefficients.

Volume (Outside and Inside bark)

Compatible stem volume equation can be readily obtained from integrating the taper function:

$$V_{sob} = \int_{h_0}^{h} \eta \, dob^2 dh \quad (3)$$

where h_0 is stump stem height and η a coefficient. Using the defined relationship (Eq. (1)), integration of Eq. (3) results in:

$$V_{sob} = \xi dbh^2 HH'^{\frac{k-\beta_1}{\beta_1}} \left\{ \begin{array}{l} \beta_1 (1-p_0)^{\frac{k}{\beta_1}} \left[1 - \left(\frac{1-p}{1-p_0} \right)^{\frac{k}{\beta_1}} \right]^{1-\theta} \left[1 - \left(\frac{1-p'}{1-p_0} \right)^{\frac{k}{\beta_1}} \right]^{\theta} \\ \qquad + a\theta\beta_2 (1-p')^{\frac{k}{\beta_2}} \left[1 - \left(\frac{1-p}{1-p'} \right)^{\frac{k}{\beta_2}} \right] \end{array} \right\} \quad (4)$$

where V_{sob} is the stem volume outside bark and ξ a coefficient.

Likewise, using *dib* in the integration results in the prediction equation of stem volume inside bark

$$(V_{sib}): V_{sib} = \zeta dbh^2 HH'^{\frac{k-\gamma_1}{\gamma_1}} \left\{ \begin{array}{l} \gamma_1 (1-p_0)^{\frac{k}{\gamma_1}} \left[1 - \left(\frac{1-p}{1-p_0} \right)^{\frac{k}{\gamma_1}} \right]^{1-\theta} \left[1 - \left(\frac{1-p'}{1-p_0} \right)^{\frac{k}{\gamma_1}} \right]^{\theta} \\ \qquad + a'\theta\gamma_2 (1-p')^{\frac{k}{\gamma_2}} \left[1 - \left(\frac{1-p}{1-p'} \right)^{\frac{k}{\gamma_2}} \right] \end{array} \right\} \quad (5)$$

where V_{sib} is the stem volume inside bark and ζ a coefficient.

Weight

Let

$$D = f(h) \quad (6)$$

where *D* is the density of wood or bark and *f* some function then stem weight can be expressed as:

$$W = \int_{h_0}^{h} D \, dV = \int_{h_0}^{h} f(h) \, dV \quad or \quad \int_{p_0}^{p} f(p) \, dV \quad (7)$$

where h_0 is the stump height and $p = \frac{h}{H}$.

Parresol and Thomas (1996) proposed a linear model for *D*:

$$D = u_0 + u_1 h + u_3 Age \quad (8)$$

where u_1, u_2, and u_3 are coefficients.

Data analysis showed that age is a predictor of stem dry weight wood only. Similarly, we investigated the impacts of treatments H and F and found that both are not significant contributors.

The distribution of wood density along stem was screened on the individual tree base and we found that a quadratic equation form may better reflect the variation of wood density along stem:

$$DWD = d_0 + d_1 h + d_2 h^2 + d_3 Age \quad (9)$$

$$GWBD = g_0 + g_1 h + g_2 h^2 \quad (10)$$

$$GWD = w_0 + w_1 h + w_2 h^2 \quad (11)$$

where *DWD, GWBD*, and *GWD* are density of dry wood, green wood and bark, and green wood, respectively, and d_0, d_1, d_2, d_3, g_0, g_1, g_2, w_0, w_1, and w_2 some coefficients.

Using the functions of wood density and volume, the weight equations can be obtained upon integrating Eq. (24):

$$
\begin{aligned}
W_{dw} = {} & (d_0 + d_1H + d_2H^2 + d_3Age)V_{sib} - \zeta k dbh^2 H^2 H'^{\frac{k-\gamma_1}{\gamma_1}} \\
& \left\{ \gamma_1(1-p_0)^{\frac{k+\gamma_1}{\gamma_1}} \left(\frac{d_1k + 2\gamma_1(d_1+d_2H)}{(k+\gamma_1)(k+2\gamma_1)} \left[1-\left(\frac{1-p'}{1-p_0}\right)^{\frac{k+\gamma_1}{\gamma_1}}\right]^{\theta} \left[1-\left(\frac{1-p}{1-p_0}\right)^{\frac{k+\gamma_1}{\gamma_1}}\right]^{1-\theta} \right.\right. \\
& \left.\left. - \frac{d_2H(1+p_0)}{k+2\gamma_1} \left[1-\left(\frac{1+p'}{1+p_0}\right)\left(\frac{1-p'}{1-p_0}\right)^{\frac{k+\gamma_1}{\gamma_1}}\right]^{\theta} \left[1-\left(\frac{1+p}{1+p_0}\right)\left(\frac{1-p}{1-p_0}\right)^{\frac{k+\gamma_1}{\gamma_1}}\right]^{1-\theta} \right) \right. \\
& \left. + \alpha'\gamma_2\theta(1-p')^{\frac{k+\gamma_2}{\gamma_2}} \left(\frac{d_1k + 2\gamma_2(d_1+d_2H)}{(k+\gamma_2)(k+2\gamma_2)} \left[1-\left(\frac{1-p}{1-p'}\right)^{\frac{k+\gamma_2}{\gamma_2}}\right] - \frac{d_2H(1+p')}{k+2\gamma_2} \left[1-\left(\frac{1+p}{1+p'}\right)\left(\frac{1-p}{1-p'}\right)^{\frac{k+\gamma_2}{\gamma_2}}\right] \right) \right\}
\end{aligned}
$$

$$
\begin{aligned}
W_{gw} = {} & (w_0 + w_1H + w_2H^2)V_{sib} - \zeta k dbh^2 H^2 H'^{\frac{k-\gamma_1}{\gamma_1}} \\
& \left\{ \gamma_1(1-p_0)^{\frac{k+\gamma_1}{\gamma_1}} \left(\frac{w_1k + 2\gamma_1(w_1+w_2H)}{(k+\gamma_1)(k+2\gamma_1)} \left[1-\left(\frac{1-p'}{1-p_0}\right)^{\frac{k+\gamma_1}{\gamma_1}}\right]^{\theta} \left[1-\left(\frac{1-p}{1-p_0}\right)^{\frac{k+\gamma_1}{\gamma_1}}\right]^{1-\theta} \right.\right. \\
& \left.\left. - \frac{w_2H(1+p_0)}{k+2\gamma_1} \left[1-\left(\frac{1+p'}{1+p_0}\right)\left(\frac{1-p'}{1-p_0}\right)^{\frac{k+\gamma_1}{\gamma_1}}\right]^{\theta} \left[1-\left(\frac{1+p}{1+p_0}\right)\left(\frac{1-p}{1-p_0}\right)^{\frac{k+\gamma_1}{\gamma_1}}\right]^{1-\theta} \right) \right. \\
& \left. + \alpha'\gamma_2\theta(1-p')^{\frac{k+\gamma_2}{\gamma_2}} \left(\left(\frac{w_1k + 2\gamma_2(w_1+w_2H)}{(k+\gamma_2)(k+2\gamma_2)} \right) \left[1-\left(\frac{1-p}{1-p'}\right)^{\frac{k+\gamma_2}{\gamma_2}}\right] - \frac{w_2H(1+p')}{k+2\gamma_2} \left[1-\left(\frac{1+p}{1+p'}\right)\left(\frac{1-p}{1-p'}\right)^{\frac{k+\gamma_2}{\gamma_2}}\right] \right) \right\}
\end{aligned}
\tag{12}
$$

$$
\begin{aligned}
W_{dw} = {} & (d_0 + d_1H + d_2H^2 + d_3Age)V_{sib} - \zeta k dbh^2 H^2 H'^{\frac{k-\gamma_1}{\gamma_1}} \\
& \left\{ \gamma_1(1-p_0)^{\frac{k+\gamma_1}{\gamma_1}} \left(\frac{d_1k + 2\gamma_1(d_1+d_2H)}{(k+\gamma_1)(k+2\gamma_1)} \left[1-\left(\frac{1-p'}{1-p_0}\right)^{\frac{k+\gamma_1}{\gamma_1}}\right]^{\theta} \left[1-\left(\frac{1-p}{1-p_0}\right)^{\frac{k+\gamma_1}{\gamma_1}}\right]^{1-\theta} \right.\right. \\
& \left.\left. - \frac{d_2H(1+p_0)}{k+2\gamma_1} \left[1-\left(\frac{1+p'}{1+p_0}\right)\left(\frac{1-p'}{1-p_0}\right)^{\frac{k+\gamma_1}{\gamma_1}}\right]^{\theta} \left[1-\left(\frac{1+p}{1+p_0}\right)\left(\frac{1-p}{1-p_0}\right)^{\frac{k+\gamma_1}{\gamma_1}}\right]^{1-\theta} \right) \right. \\
& \left. + \alpha'\gamma_2\theta(1-p')^{\frac{k+\gamma_2}{\gamma_2}} \left(\frac{d_1k + 2\gamma_2(d_1+d_2H)}{(k+\gamma_2)(k+2\gamma_2)} \left[1-\left(\frac{1-p}{1-p'}\right)^{\frac{k+\gamma_2}{\gamma_2}}\right] - \frac{d_2H(1+p')}{k+2\gamma_2} \left[1-\left(\frac{1+p}{1+p'}\right)\left(\frac{1-p}{1-p'}\right)^{\frac{k+\gamma_2}{\gamma_2}}\right] \right) \right\}
\end{aligned}
\tag{13}
$$

where W_{dw}, W_{gwb}, and W_{gw} are stem weight of dry wood, stem weight of green wood and bark, and stem weight of green wood, respectively.

RESULTS

Treatment Effect

There is evidence that treatment F has impacted the upper segment taper, though treatment H did not affect these variables very much. To reflect this fact, the value of the upper segment form factor (b_2 or g_2) should be different for fertilized trees and unfertilized trees.

Estimation of Coefficients

Note that the derived stem taper and volume equations share not only independent variables such as *p*, *dbh*, etc. but also coefficients like b_1 and b_2. System modeling is required for obtaining efficient estimates of parameters because the estimation of shared coefficients needs the information from all associated dependent variables, i.e., both taper and volume. Note that V_{sob} and V_{sib} are endogenous variables because they appear on both sides of volume and weight equations. To eliminate simultaneous equation bias, predicted rather than observed V_{sob} and V_{sib} values were used as regressors in weight equations during parameter estimation (Borders and Bailey, 1986).

Table 1—Estimates of parameters with standard errors (in second line)

dob	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_{2f}$	p'
	0.1569	0.1441	0.1561	0.6025
	0.0005	0.0007	0.0007	0.0092
dib	c	$\hat{\gamma}_1$	$\hat{\gamma}_2$	$\hat{\gamma}_{2f}$
	0.8625	0.1724	0.1428	0.1588
	0.0035	0.0011	0.0008	0.0008
V_{sob}	ξ			
	1.99E-4			
	3.60E-7			
V_{sib}	ζ			
	1.59E-4			
	6.19E-7			
W_{dw}	d_0	d_1	d_2	d_3
	367.63	-5.95	-5.70E-2	12.82
	13.73	7.82E-1	1.31E-2	1.69
W_{gwb}	g_0	g_1	g_2	
	767.38	21.96	5.23E-2	
	5.72	4.50E-1	7.42E-3	
W_{gw}	w_0	w_1	w_2	
	784.88	21.68	1.86E-1	
	7.04	*5.72E-1*	*8.97E-3*	

Table 2—Fit statistics of each equation in the taper-volume-weight equation system, where MB is the mean bias, RMSE the root mean square error, and EF the modeling efficiency

Equations	MB	RMS	EF
dob	0.2667 (cm)	1.1841 (cm)	0.9621
dib	0.4736 (cm)	1.1042 (cm)	0.9545
V_{sob}	6.30E-4 (m^3)	0.0092 (m^3)	0.9900
V_{sib}	8.20E-4 (m^3)	0.0099 (m^3)	0.9835
W_{dw}	-5.34E-1 (kg)	2.17 (kg)	0.9966
W_{gwb}	3.68E-1 (kg)	9.17 (kg)	0.9890
W_{gw}	-3.10E-1 (kg)	9.12 (kg)	0.9870

The mixed-effects systematic modeling technique was applied for obtaining unbiased and consistent estimates of parameters. The modeling efficiency (EF), root mean square error (RMSE), and mean bias (MB) (Loague and Green, 1991, Mayer and Butler 1993) were applied as fit statistics. The estimates of coefficients involved are listed in table 1 with the fit statistics in table 2.

DISCUSSION AND CONCLUSION

Compared with an empirical taper equation, the one derived from geometric relationships is more theoretically sound and physically meaningful and reduces the parameters dramatically, which simplifies model structure and helps parameter estimation in nonlinear regression.

Resultant taper equations showed that two segments well depict the relationship between stem diameter and height for trees in this study. The above conclusion does not go with Fang and others.'s (2000) where three segments are required. A plausible explanation for this disagreement might be the fact that the stems used in this work are relatively young and do not exhibit much butt swell.

Fig. (2) shows the profiles of *dob* and *dib* using a 18 meters long stem with *dbh* 20 centimeters for unfertilized and fertilized trees, implying a significant fertilizer impact for both inside and outside bark diameters on upper segment. Specifically, fertilized trees have less taper than unfertilized trees, implying more volume and woody materials on the upper stem of fertilized trees.

In this study, we derived segmented stem weight equations by integrating wood density and segmented volume. This approach provides logical estimates of wood density for any segment along the stem. This is especially noteworthy since previously derived equations overpredict wood density in the upper part of stems. Yet, the fact that fertilization did not significantly affect the unit-weight of stem wood agrees with the results of data analysis and conclusions derived from the investigation done by [1]Clark using the same data (personal communication).

It should be noted that this system of stem taper-volume-weight equations was fitted to a small database from a specific geographic location. Thus, any use of these functions should first be validated on independent data. The objective here was not to produce equations that will be widely used by practitioners but to develop a modeling framework that is flexible enough to reflect the impacts of various silvicultural treatments. As such, these equations provide researchers a useful tool for simulating the impact that fertilization may have on stem form, volume, and weight.

ACKNOWLEDGMENTS

Authors wish to gratefully acknowledge the support from the sponsors of the Consortium for Accelerated Pine Plantation Studies, Boise Cascade Corporation, Champion International Corporation, Gilman Paper Company, International Paper Company, Jefferson Smurfit Group, Mead Coated Board, Rayonier Industry,

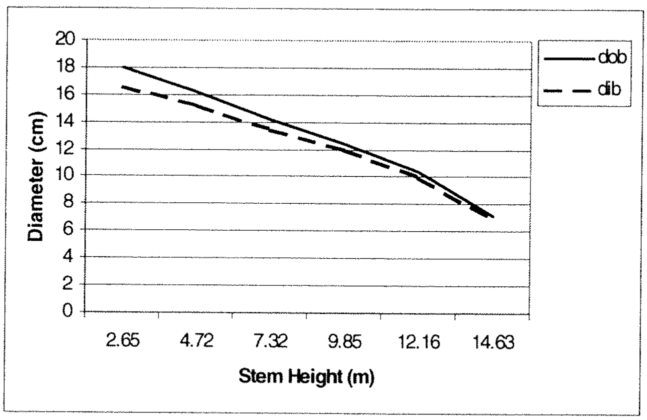


Figure 1—Stem taper profile of a tree at age 12, where *dob* is the stem diameter outside bark and *dib* the stem diameter inside bark.

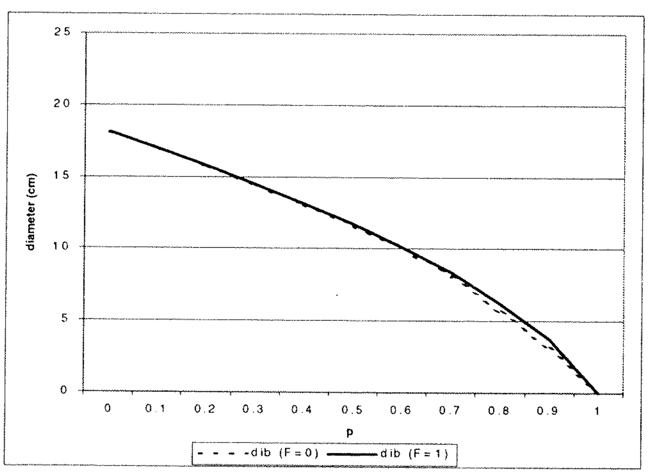


Figure 2a—Stem taper profiles of diameter outside bark *dob*) for fertilized (F = 1) and unfertilized (F = 0) trees with total height 18 meters and *dbh* 20 centimeters, where *p* is the ratio of stem height to total height.

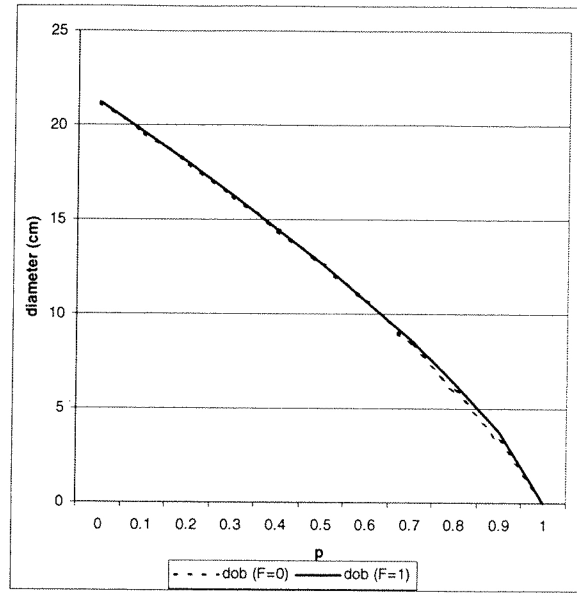


Figure 2b—Stem taper profiles of diameter inside bark (*dib*) for fertilized (F = 1) and unfertilized (F = 0) trees with total height 18 meters and *dbh* 20 centimeters.

Temple-Inland Industry, The Timber Company, Union Camp Corporation, US Alliance, Westvaco Corporation, and Weyerhaeuser Company.

REFERENCES

Allen, H.L.; P.M. Dougherty; R.G. Campbell. 1990. Manipulation of water and nutrients-practice and opportunity in southern U.S. pine forests. Forest Ecology Management. 30: 437-453.

Bailey, R.L. 1994. A compatible volume-taper model based on the Schumacher and Hall generalized constant form factor volume equation. Forest Science. 40: 303-313.

Borders, B.E.; R.L. Bailey. 1986. A compatible system of growth and yield equations for slash pine fitted with restricted three-stage least squares. Forest Science. 32: 185-201.

Borders, B.E.; R.L. Bailey. 1997. Loblolly pine: Pushing the limits of growth. Consortium on Accelerated Pine Production Studies. Technical Report CAPPS 1997-1. The University of Georgia, Cooperative Extension Service, Forest Resources Publication. January 1997.

Broad, L.R.; G.C. Wake. 1995. Derivative based methods for constructing volume-ratio and taper equations. Forest Science. 41: 157-167.

Byrne, J.C.; D.D. Reed. 1986. Complex compatible taper and volume estimation systems for red and loblolly pine. Forest Science. 32: 423-443.

Clutter, J.L. 1980. Development of taper functions from variable-top merchantable volume equations. Forest Science. 26: 117-120.

Demaerschalk, J.P. 1972. Converting volume equations to compatible taper equations. Forest Science. 18: 241-245.

Fang, Z.; R.L. Bailey. 1999. Compatible volume and taper models with coefficients for tropical species on Hainan Island in southern China. Forest Science. 45: 85-100.

Fang, Z.; B.E. Borders; R.L. Bailey. 2000. Compatible volume-taper models for loblolly and slash pine based on a system with segmented-stem form factors. Forest Science. 46:1-12.

Ford, E.D. 1984. The dynamics of plantation growth. In: Nutrition of plantation forests. Bowen, G.D.;E.K.S. Nambiar, eds. London: Academic Press: 17-52.

Forslund, R.R. 1982. A geometrical volume model based on the location of the center of gravity of the bole. Canadian Journal of Forest Research. 12: 215-221.

Gent, J.A.; H.L. Allen; R.G. Campbell. 1986. Phosphorous and nitrogen plus phosphorous fertilization in loblolly pine stands at establishment. Southern Journal of Applied Forestry 10(2): 114-117.

Jokela, E.L.; S.C. Stearns-Smith. 1993. Fertilization of established southern pine stands: effects of single and split nitrogen treatments. Southern Journal of Applied Forestry 17(3): 135-138.

Loague, K.; R.E. Green. 1991. Statistical and graphical methods for evaluating solute transport models: overview and application. J. Contam. Hydrol. 7: 51-73.

Mayer, D.G.; D.G. Butler. 1993. Statistical validation. Ecol. Model. 68: 21-32.

McTague, J.P.; R.L. Bailey. 1987. Simultaneous total and merchantable volume equations and a compatible taper function for loblolly pine. Canadian Journal of Forest Research. 17: 87-92.

Newberry, J.D.; H.E. Burkhart; R. L. Amateis. 1989. Individual tree merchantable estimating system. Canadian Journal of Forest Research. 19: 679-683.

Ormerod, D.W. 1973. A simple bole model. For. Chron. 59: 136-138.

Parresol, B.R.; Thomas, C.C. 1996. A simultaneous density-integral system for estimating stem profile and biomass: slash pine and willow oak. Canadian Journal of Forest Research. 26: 773-781.

Stearns-Smith, S.C.; E.J. Jokela; R.C. Abt. 1992. Thinning and fertilizing southern pine stands of the lower coastal plain: biological and economical effects. Southern Journal of Applied Forestry. 16(4): 186-193.

A MODEL FOR DEFINING AND PREDICTING THE URBAN-WILDLAND INTERFACE FOR THE PIEDMONT OF SOUTH CAROLINA

Mary L. Webb Marek and Lawrence R. Gering[1]

Abstract— Resource managers continue to experience a deluge of management conflicts as urban population centers expand into areas that were formerly wildland settings. Traditional forest management practices, fire suppression, recreational opportunities and wildlife management are activities that have become contentious in many locales. A better understanding of the interface zones between these two types of land use is important if managers are to successfully maintain the values of such lands. A model for defining the urban-wildland interface for the Piedmont of South Carolina (Anderson, Oconee, and Pickens Counties) was developed, allowing identification of these transitional zones. Landsat TM and SPOT images provided a description of the current land cover and land use of the study area. Census data were used to obtain information on housing densities, population densities, and other social and cultural activities. Additional data (such as digital road maps) were processed and added to the ArcView-based GIS structure. On-site ground truthing was also conducted. This procedure created a snapshot view of current interface zones and provides a foundation for developing a dynamic model designed to predict future change.

INTRODUCTION

The objective of this study is to develop a process for determining the urban-wildland interface within Anderson, Oconee, and Pickens Counties in South Carolina using social, economic, and land use/land cover data through the use of a desktop geographic information system (GIS).

The idea of urban-wildland interface is a relatively new problem in natural resource management. The growth of the United States as a nation over the past two centuries is intricately tied to the concept of the conflict between urban development and pre-existing wildland. Between 1970 and 1990, the United States population increased by 22.5 percent with 21 million acres being converted to more urban land uses (Garkovich 2000).

According to a recent Sierra Club report, South Carolina lags behind the rest of the nation in terms of open space protection, ranking third to the last among the fifty states (Romain 2000). This situation has sparked valid concerns of urban sprawl in the Upstate of South Carolina. As the metropolitan areas of Greenville, SC; Atlanta, GA; and Charlotte, NC continue to expand, the counties located just outside of and between these cities will continue to provide evidence of this rural to urban transition. Concerned residents and politicians have formed groups focused on the protection of specific open spaces. Some of such groups include Upstate Forever, Friends of the Reedy River, and a Committee of Changing Land Use and Environment (CLUE). While the concept of multiple use is widely acknowledged and often practiced, the problem of externalities on the urban-wildland interface presents a particularly difficult management challenge because of the concentrated nature of the activities. These changes in land use have sparked many conflicts, making natural resource management more difficult and creating the need for identification of these urban-wildland interface areas. Management of these areas requires that one must understand the various land cover, economic, social, political, and historical factors that are involved in the make up of these zones. From this information, a definition can then be developed and the existence of these interface zones may be predicted and appropriate management concepts applied.

METHODS

A GIS database can be a vital tool within many different professions and especially in the management of natural resources because of its integral spatial component. Predictive modeling, as demonstrated in this study, is a common application of GIS technology. Within ArcView GIS, queries can easily be built and the results visually displayed. The query tool in ArcView allows an analyst to select features and records in a table that relate to attributes of the map data.

For this study, data from the 1990 United States Census (median household income, housing density, roads and municipalities) and 1992 satellite imagery (Landsat Thematic Mapper imagery of land use/land cover) were combined to get a definition of the urban-wildland interface.

[1]Graduate Student, Assistant Professor, Department of Forest Resources, Clemson University, Clemson, SC, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

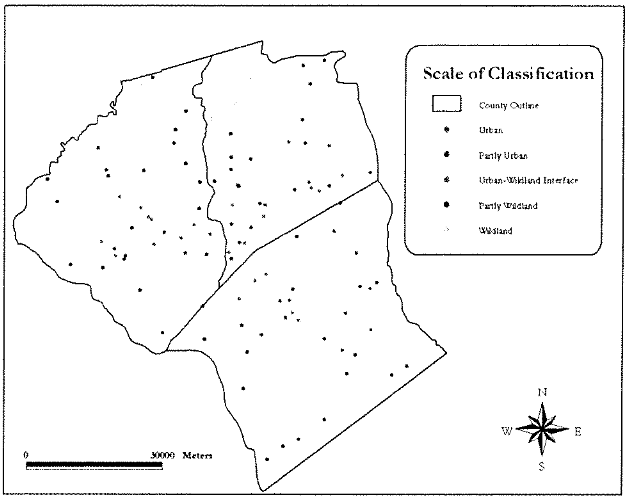


Figure 1—GPS Data from Preliminary Sample.

In order to develop a reasonable query for urban-wildland interface, a preliminary sample of global positioning system (GPS) data was taken using a Trimble GeoExplorer II. Points were collected randomly along roadsides within the tri-county area. Each point was classified along a scale of urban to wildland based on observation. Although this appears to be a subjective task, much of the process was based on the Anderson Level II Land Use Classification System (Anderson 1976). The map in figure 1 depicts the scale of classification used and the preliminary sample of GPS data.

The "GPSed" points were examined to determine statistical trends in each classification. Queries were then conducted to identify where urban-wildland interface areas were located. Once the queries were completed, a verification sample of 125 points was collected, again using GPS technology, to compare the queried data with on-site observations (ground-truthing).

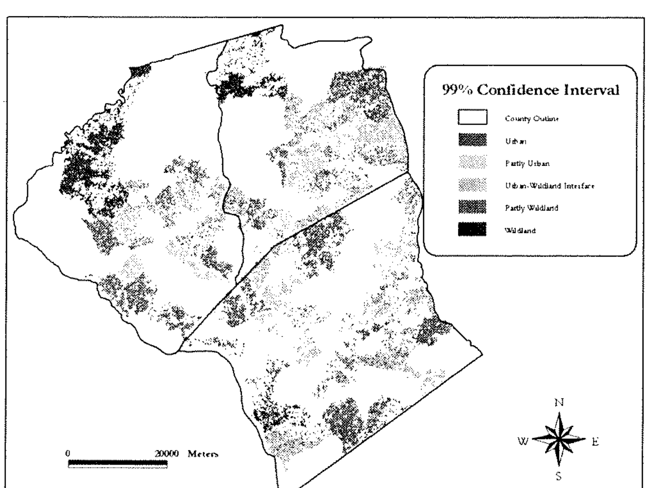


Figure 2—Query Results from 99 Percent Confidence Interval on Housing Density and Median Household Income.

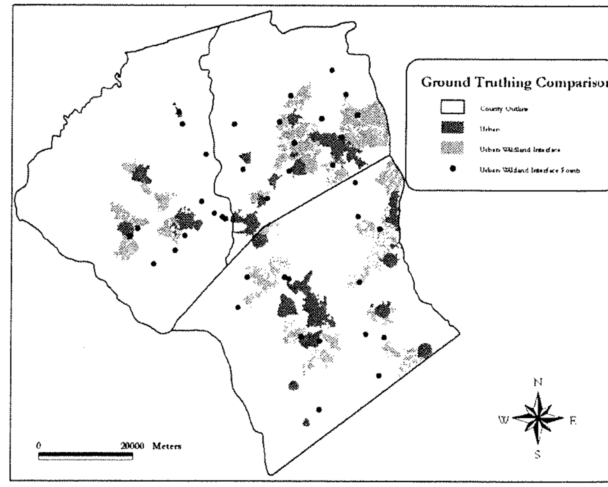


Figure 3—Urban-Wildland Interface Verification Sample Compared with 99 Percent Confidence Interval Query.

RESULTS

The initial map queries of each classification included 90 percent, 95 percent, 99 percent confidence intervals based on median household income and housing density because these were the quantitative variables used in the study. These queries also specified land use/land cover types which occurred 30 percent or more of the time in each urban to wildland classification. Figure 2 depicts the results from the 99 percent confidence interval query.

Figure 3 focuses on the query results for urban-wildland interface, comparing those areas with urban-wildland interface points collected in the verification sample. Local municipalities were displayed for location reference. Here, a total land area of 635 square kilometers meets the criteria from the query for urban-wildland interface. Points from the verification sample allow one to examine the veracity of the query results. Some points lay directly on urban-wildland interface, indicating agreement between the query criteria and on-site observations. Other points lay just

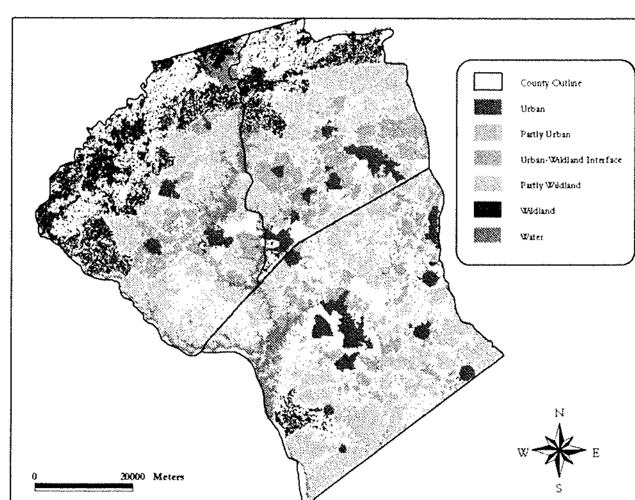


Figure 4—Extended Query Results.

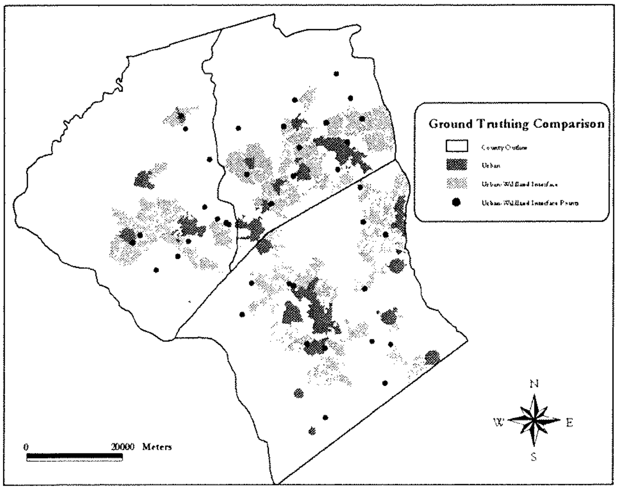


Figure 5—Urban-Wildland Interface Verification Sample Compared with Extended Query.

outside of or along the outskirts of urban-wildland interface, indicating partial agreement between the query data and on-site observations. Still other points remain in question, lying on areas for which census data were not available, and therefore, not answered by the urban-wildland interface query.

Because of overlapping data from the initial queries, each classification was separated based on housing, with higher densities depicting more urban areas. The queries were further refined by extending the ranges within each classification and by requesting urban areas to reflect municipality boundaries. Figure 4 depicts the results from this extended query. This map shows a more logical pattern for locations of each classification, where urban areas blend into interface areas, which in turn, blend into wildland areas.

Figure 5 focuses on the results from the extended query for urban-wildland interface, as compared with the verification points for urban-wildland interface. This query indicates that a total area of 1061 square kilometers meet the criteria for urban-wildland interface, nearly 1/5th of the entire tri-county area. This map shows more agreement between the verification points and the query results. That agreement reflects accuracy within the queries, and depicts the locations of urban-wildland interface. However, points of partial agreement and points of question still exist. It is yet to be determined what may be occurring in these areas. Perhaps they have outlying values in the housing density or median household income variables, which would prevent these regions from meeting the query criteria for urban-wildland interface. A revisit to these points may answer some of these questions.

CONCLUSION

This study reveals that using social, economic, land use/ land cover data may define urban-wildland interface locations. Maps like these could be used as a tool for development and land management planning, especially where conflicts exist or may arise. These maps allow land managers to easily identify and focus on regions of concern. They provide information for not only land managers and developers, but also for interested community members and local residents within areas experiencing land use changes.

This study could be further expanded to examine interface in larger regions using additional social and economic variables. The added information would provide an even more detailed definition, applicable to more communities. The model could also be adjusted to depict future change, by including a variable representing time.

REFERENCES

Anderson; Hardy; Roach; Witmer. 1976. "A Land Use and Land Cover Classification System for Use with Remote Sensor Data." USGS Professional Paper. No. 964. 28 p.

Garkovich; Lorraine. 2000. Land Use at the Edge: The Challenges of Urban Growth for the South. The Southern Rural Development Center, No. 13, August.

Romain, L. 2000. Greenville rec chief: Buy Land Now or Miss Out. The Greenville News, March 25, 13A.

THE EFFECT OF DENSITY ON THE HEIGHT-DIAMETER RELATIONSHIP

Boris Zeide and Curtis Vanderschaaf[1]

Abstract—Using stand density along with mean diameter to predict average height increases the proportion of explained variance. This result, obtained from permanent plots established in a loblolly pine plantation thinned to different levels, makes sense. We know that due to competition, trees with the same diameter are taller in denser stands. Diameter and density are not only necessary, but may be sufficient for determining tree height because other factors affecting height are reflected by diameter and density. In the process of developing the proposed model we found that height increases monotonically with density and that this increase is not bounded by an asymptote. Contrary to our expectations, the inclusion of density did not bring the allometric parameter of diameter closer to the theoretical value of 2/3.

INTRODUCTION

By relating height and diameter we can express height from diameter, which can be measured easier and more reliably. This relationship also informs us about stem taper and, therefore, volume. As a result, the height-diameter relationship is one of the most studied in forestry. Although diameter is a good predictor of height, we may advance further by using other available information. Diameter explains a lot of variation in height. After all, it is designed to support the load that depends on tree height. Still, there are other factors determining the load that may modify the height-diameter relationship. The most obvious among these factors is stand density.

APPROACH AND BASIC ASSUMPTIONS

Theoretical and empirical studies of the height-diameter relationship suggest that it is an allometric function with the power of diameter, *b*, equal to 2/3 (Greenhill 1881, McMahon 1973, Norberg 1988, O'Brien and others 1995):

$$H = aD^b \qquad (1)$$

This relationship describes a column of equal resistance to bending and buckling, which is a reasonable assumption for tree stems exposed, in addition to the force of gravity, to wind (O'Brien and others 1995, Schniewind 1962) and snow (King and Loucks 1978, McMahon and Bonner 1983). Such a column maintains elastic similarity along the stem (Rich 1986, Rich and others 1986). Elastic similarity leads to b=2/3 and allows the tree to maintain a constant safety factor against both buckling and bending due to tree weight and wind force (McMahon and Bonner 1983, Norberg 1988, Rich and others 1986).

Besides purely structural considerations, there is a biological component. Trees have evolved to equalize not so much the strength along the stem as to equalize the damage to its survival. Below the crown this biological requirement coincides with the mechanical one because at any point breakage dooms the tree. The situation inside the crown is different. Trees may survive the loss of a third of the crown and more. Therefore, it would not pay to invest into equal strength of the upper stem. Indeed, trees often lose tree tops, most frequently within the upper third of the crown.

Equation (1) assumes that height depends exclusively on diameter. This is not true: in dense stands trees with the same diameter are taller than those in less dense stands. Therefore, stand density should be included as the second predictor of average height. Out of many ways to incorporate density into the predicting equation, we tested several asymptotic and non-asymptotic density modules (table 3).

As the measure of density we used Reineke's Stand Density Index (SDI) (Reineke 1933):

$$SDI = N^*(D/10)^{1.7} \qquad (2)$$

where: N = number of trees per acre, D = quadratic mean diameter of a stand. The power of 1.7 was provided by MacKinney and others (1937) who reanalyzed the data used by Reineke (1933) with standard statistical methods. Sometimes it is convenient to normalize the index by dividing it by the maximum value of 450 which was reported by Reineke for loblolly pine:

$$I = (N^*(D/10)^{1.7})/450 \qquad (3)$$

Density does not affect height prior to the onset of competition, which happens, according to our observations when Reineke's index is 34. This minimal level of density, denoted as I0 = 34/450, is used in the following models to set the initial effective density to 1.

[1]Professor and Research Specialist, School of Forest Resources, University of Arkansas, Monticello, AR 71656-3468, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Quadratic mean diameter (D - in inches) and average total tree height (H - in feet) by TBA (target basal area in square feet per acre) treatment from the Monticello thinning and pruning study. No measurements were conducted prior to age 27 for the Control TBA, and no height measurements were conducted at age 37 for any density. The Control TBA had an average basal area of 137 square feet per acre across all

	TBA									
Age	-- 30 --		-- 50 --		-- 70 --		-- 90 --		**Control**	
	D	H	D	H	D	H	D	H	D	H
12	6.0	36.4	6.9	37.2	6.6	36.6	6.6	35.9	.	.
15	9.1	43.6	8.7	44.2	8.0	43.7	7.8	43.3	.	.
16	9.7	46.3	9.4	48.1	8.6	46.8	8.2	46.0	.	.
19	11.7	51.8	11.1	51.5	9.9	51.2	9.4	49.0	.	.
24	14.4	61.2	13.5	64.3	12.0	62.8	11.1	61.0	.	.
27	16.2	67.2	15.0	69.4	13.4	68.7	12.3	67.1	9.9	58.2
30	18.4	73.5	16.8	75.5	14.9	74.5	13.7	74.2	10.8	65.7
35	21.1	77.5	19.1	80.3	16.9	79.8	15.4	79.7	11.6	72.8
37	21.8	-	19.7	-	17.4	-	16.0	-	12.6	-
40	22.7	84.7	20.6	86.6	18.3	86.0	16.7	86.5	12.8	78.6

DATA

We used data collected during ten measurements on 40 permanent plots (table 1) established in 1970 by the Southern Forest Experiment Station in a typical 12-year-old loblolly pine (*Pinus taeda L.*) plantation in southeast Arkansas (Burton 1981). This is the second oldest active thinning and pruning study in loblolly pine stands. What makes these data particularly suitable for this research is the wide range of density. Plots were initially thinned at age 12 to 40, 60, 80 and 100 feet^2/ac of basal area. After the second inventory at age 15, basal areas were reduced to 30, 50, 70 and 90 feet^2/ac (TBA) and maintained at these levels by subsequent thinnings at ages 24, 27, 30, 35, and 40. The density variation was further enhanced by three severe ice storms. At the age of 27 five control plots (without thinning) were established on the adjacent untreated portion of the plantation.

DOES DENSITY HELP TO PREDICT HEIGHT WHEN DIAMETER IS KNOWN?

Before designing a model to predict height using diameter and density, we would like to make sure that the density effect is significant. Two methods were used for this purpose. First, we fitted the traditional allometric model relating height and diameter (equation (1)) to five groups of plots differing in density. The equation was linearized by log-transforming the variables. We found that predicted average heights of the stands with the same diameter (average quadratic mean diameter across all treatments and ages) increased with stand density level (table 2). The height difference between the extreme levels of density is 21 feet. Parameter *b* also showed an increasing trend in managed stands. Its pooled value is 0.7374, which is slightly greater than 2/3, probably because of the unaccounted effects of density.

The second method is to test several models including density as a predictor along with diameter (table 3). In all tested models the parameter of density was significantly different from 0, which indicates that, regardless of equation form, density does help to predict height when diameter is known. The inclusion of density increased the proportion of explained variation in height from 0.88 to 0.93.

IS THERE AN OPTIMAL DENSITY FOR HEIGHT GROWTH?

Now that we are sure that density is an important predictor of height, we want to know whether there is a density at which height reaches its maximum for a given diameter. Discovering such an optimal density would be of help to foresters who are interested in maximizing height growth.

To solve this question, we used a model flexible enough to locate a possible culmination of height. To this end, our model includes two density terms, driven by density (I), and density squared (I^2):

$$H = aD^{b}e^{cI+g(I*I)} \quad (4)$$

If *c* and *g* are both positive, there is no maximum height. If *c* and *g* are both negative, then our logic and analytical procedures are entirely incorrect because this would mean that height decreases when density increases. But, if *c* is positive and *g* is negative then there is a maximum height.

The results (c = 0.9412 g = -0.6180) show that there is an optimal density, that is the density at which height reaches a maximum. This conclusion contradicts our understanding of the involved processes. We believe that when diameters are equal, average height increases with increasing density. Should we trust the parameter values obtained from a limited data set or our reasoning? Fortunately, this contradiction can be resolved by calculating the value of the

Table 2—Comparison of the relationship between height and diameter by density treatment fitted to data from the Monticello thinning and pruning study. Where D = quadratic mean diameter in inches, H = average height in feet (height corresponding to D), Obs. = number of observations, Den = square feet of basal area per acre, SEE = standard error of the estimate, Hest = average height in feet estimation of a stand with a QMD of 13 inches (average size of D across all treatments and ages), SEE = standard error of the estimate, Adj. R^2 - is the adjusted R-squared value. Variables were log-transformed prior to fitting. The number after ± represents the single standard error

Equation	Obs.	Den	a	b	SEE	Adj. R^2	Hest
$H = aD^b$	90	32	9.7834 ±0.4197	0.6855 ±0.0160	0.0596	0.9538	57
$H = aD^b$	90	51	8.3875 ±0.3441	0.7730 ±0.0157	0.0533	0.9646	61
$H = aD^b$	90	69	7.8677 ±0.2680	0.8259 ±0.0136	0.0436	0.9764	65
$H = aD^b$	90	85	6.5471 ±0.2638	0.9194 ±0.0165	0.0486	0.9720	69
$H = aD^b$	19	137	9.3161 ±2.8621	0.8263 ±0.1105	0.0598	0.7532	78

optimal density, I^*, which can be obtained from the following equation:

$$dH/dI = H(c+2gI) = 0 \quad (5)$$

Hence $I^* = -c/2g = 0.7615$. This value is beyond the data range: the actual maximum density of the data is 0.7017. This means that the discovered optimum is illusory. The negative term indicates that the relationship between height and density is not linear but concave down.

IS THE RELATIONSHIP BETWEEN DENSITY AND HEIGHT ASYMPTOTIC?

The next question is: does the discovered concave form approach a finite maximum height or is the height increase unlimited? The asymptotic form means that when density is high further increase will produce practically no increase in height, which is not likely. We believe that the non-asymptotic form is more biologically reasonable. Besides this somewhat intuitive reasoning, we tested both asymptotic and non-asymptotic log-transformed models to estimate height using diameter and density as predictors. As it turned out, the non-asymptotic models are slightly more precise. To make sure that this result is not an artifact of a specific equation form, we tested models of each form (table 3). For practical use we recommend the most precise model, the last in table 3.

CONCLUSIONS

Diameter and height provide us information about stem taper and ultimately tree volume. Often height is estimated using the easier obtained diameter. However, prediction of height using only diameter does not account for differences in stem taper associated with changes in density for stands of the same diameter. Density helps to explain variation in height and therefore needs to be included into the height-diameter relationship. The relationship between height of trees with the same diameter and density is concave down. Yet, it is not bounded by an asymptote. The model we recommend (table 3) satisfies all the considered requirements. It is also the most precise.

Still, we are not totally happy with our results. We expected that the introduction of density as a predictor would bring the value of parameter *b* closer to its theoretical value of 0.67. We failed in this respect: the excess of parameter b over 0.67 increased from 0.07 to 0.15 (table 3). Further studies need to be conducted to develop a density module that is both efficient in explaining variation in height and provides *b* with a value close to that predicted theoretically.

Table 3—Comparison of the relationships between height, diameter, and density fitted to 379 obs. from the Monticello thinning and pruning study. D = quadratic mean diameter in inches, H = average height in feet (height corresponding to D), SDI = Reineke's stand density index, SDI0 = minimum value of SDI (onset of competition) equal to 34.03, SEE = standard error of the estimate, Adj. R^2 - is the adjusted R-squared value. Variables were log-transformed prior to fitting. The number after ± represents the single standard error

Equation	a	b	c	SEE	Adj. R^2
		Normal height-diameter relationship			
$H = aD^b$	9.4734	0.7374		0.0981	0.8763
	± 0.3443	±0.0142			
		Height-diameter relationship with an asymptotic density module			
$H = aD^{b*}$	6.4200	0.8196	0.0723	0.0756	0.9266
$(2-e^{-cSDI/SDI0})$	±0.2567	±0.0121	±0.0074		
		Height-diameter relationship with a non-asymptotic density module			
$H = aD^{b*}$	5.8751	0.8210	0.1945	0.0750	0.9278
$(1+SDI/SDI0)^c$	±0.2392	±0.0120	±0.0118		
$H = aD^{b*}$	6.5875	0.8223	0.1422	0.0749	0.9280
$(SDI/SDI0)^c$	±0.2353	±0.0120	±0.0086		

REFERENCES

Burton, J.D. 1981. Thinning and pruning influence glaze damage in a young loblolly pine plantation. Research Note SO-264. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Greenhill, G. 1881. Determination of the greatest height consistent with stability that a vertical pole or mast can be made, and of the greatest height to which a tree of given proportions can grow. Proc. Cambridge Philosophical Society. 4: 65-73.

King, D.A., and O.L. Loucks. 1978. The theory of tree bole and branch form. Radiation and Environmental Biophysics. 15: 141-165.

MacKinney, A.L., F.X. Schumacher, and L.E. Chaiken. 1937. Construction of yield tables for nonnormal loblolly pine stands. Journal of Agriculture Research. 54: 531-545.

McMahon, T.A. 1973. Size and shape in biology. Science. 179: 1201-1204.

McMahon, T.A. and J.T. Bonner. 1983. On size and life. New York: Scientific American Books.

Norberg, R.A. 1988. Theory of growth geometry of plants and self-thinning of plant populations: geometric similarity, elastic similarity, and different growth modes of plants. American Naturalist. 131: 220-256.

O'Brien, S.T., S.P. Hubbell, P. Spiro, R. Condit, R.B. Foster. 1995. Diameter, height, crown, and age relationships in eight neotropical tree species. Ecology. 76: 1926-1939.

Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. Journal of Agricultural Resources. 46: 627-638.

Rich, P.M. 1986. Mechanical architecture of arborescent rain forest palms. Principes. 30:117-131.

Rich, P.M., K. Helenurm, D. Kearns, S.R. Morse, M.W. Palmer, L. Short. 1986. Height and stem diameter relationships for dicotyledonous trees and arborescent palms of Costa Rican tropical wet forest. Journal of the Torrey Botanical Club. 113: 241-246.

Schniewind, A.P. 1962. Horizontal specific gravity variation in tree stems in relation to their support function. Forest Science. 8: 111-118.

INTERIM TAPER AND CUBIC-FOOT VOLUME EQUATIONS FOR YOUNG LONGLEAF PINE PLANTATIONS IN SOUTHWEST GEORGIA

John R. Brooks, Stacey Martin, Jeff Jordan, and Chris Sewell[1]

Abstract— Outside bark diameter measurements were taken at 0, 0.5, 2.0, 4.5, 6.0, 16.6 and 4 foot height intervals above 6 foot to a 2 inch dob top diameter on 42 longleaf pine trees selected from intensively managed longleaf pine (*Pinus palustris Mill.*) plantations in Dougherty and Worth Counties in southwest Georgia. Trees were sampled from unthinned, cutover stands in their 11th and 14th growing season that are currently part of an existing growth and yield study. Sample trees ranged from 2 to 7 inches in diameter and from 18 to 40 feet in total height. Parameters for a segmented polynomial taper and compatible cubic foot volume equation were simultaneously estimated using a seemingly unrelated nonlinear fitting procedure to volumes based on a generalized Newton formula and an overlapping bolt methodology. Resultant taper and volume functions were compared to published equations for longleaf plantations in the West Gulf physiographic region.

INTRODUCTION

Over the past decade there has been an increased interest in planting longleaf pine (*Pinus palustris Mill.*) in southwest Georgia. This interest is based on a historical, as well as an emotional relationship with this species, the existence of cost sharing programs, and the ability to consistently establish well stocked, uniform plantings that generally do not exhibit a "grass-stage". The ability to establish these types of plantings is based on major advancements in seedling care, planting techniques, more intensive site preparation methods and inclusion of post planting herbaceous weed control.

Little is known regarding the growth and yield of longleaf plantations in the Southeast, especially for these more intensively managed plantations. Most of the published mensurational information on planted longleaf stands has been for cutover sites in the West Gulf physiographic region. Compatible taper and volume functions have been published for outside bark diameters (Baldwin and Polmer 1981) and inside bark diameters (Thomas and others 1995) for plantations in central Louisiana and east Texas. A total and merchantable cubic foot volume equation has also been developed from plantations in this same region by Baldwin and Saucier (1983). Whether these equations accurately model the taper and volume of trees in southwest Georgia has never been examined.

The purpose of this project was to develop compatible taper and cubic foot volume functions as part of a growth and yield study for unthinned longleaf pine plantations on cutover sites in southwest Georgia and to compare the resulting equations with those that have been developed for longleaf pine plantations in the West Gulf.

METHODS

Sample trees were selected during the summer of 2000 from three unthinned plantations in Dougherty and Worth Counties, Georgia that are part of an existing growth and yield study. Plantations were established on cutover stands that received mechanical as well as chemical site preparation. Plantations ranged in age from 12 to 14 years and were established on sandy loam soils using bare root seedlings. A description of these plantations is presented in table 1.

Approximately 15 sample trees were selected from the interior of each plantation from the area buffering existing permanent growth and yield plots. An attempt was made to stratify the sample by diameter class without leaving holes in the existing stand. Sample tree distribution by height and diameter class is displayed in table 2. Trees possessing multiple stems, broken tops, obvious cankers or crooked boles were not included in the sample. Each sample tree was felled at ground level and total tree height recorded to the nearest 0.1 foot. One inch sample disks were removed from the base, 0.5 foot, 2.0 feet, 4.5 feet, 6.0 feet and repeatedly along the stem at 4 foot intervals until reaching a 2 inch dob top diameter. An additional disk was also removed at 16.6 feet to represent Girard form class height. Diameter outside bark to the nearest 0.01 inch was measured for each disk using a diameter tape. The data set included 456 outside bark measurements on 42 sample trees. Cubic foot volume outside bark was calculated for each bolt utilizing an overlapping bolt method (Bailey, 1995) and a generalized Newton formula described by Wiant and others (1992).

---

[1]Biometrician, F&W Forestry Services, Inc., Albany, GA; Research Coordinator, University of Georgia, Athens, GA; Inventory Supervisor; Appraiser, F&W Forestry Services, Inc., respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

DATA ANALYSIS

The Max and Burkhart (1976) segmented polynomial taper function was selected as the first candidate taper model, which has the form:

$$\frac{d^2}{D^2} = \beta_1(Z_u - 1) + \beta_2(Z_u^{\,2} - 1) + \beta_3(\alpha_1 - Z_u)^2 I_1 + \beta_4(\alpha_2 - Z_u)^2 I_2 \quad (1)$$

Where d is diameter outside bark (in.) at some given height h (feet), D is diameter outside bark (in.) at breast height, Z_u is the ratio of the upper bolt height to total height, α_1 and α_2 represent the joint points estimated during the fitting procedure, and the ß's are model parameters. The I_i's are indicator variables and are defined as:

$$I_i = \begin{cases} 1, \text{if } Z_u \le \alpha_i \\ 0, \text{if } Z_u \succ \alpha_i \end{cases}$$

Integration of the taper function over height results in the volume model:

$$V = kD^2H \begin{Bmatrix} \frac{\beta_2}{3}(Z_u^3 - Z_l^3) + \frac{\beta_1}{2}(Z_u^2 - Z_l^2) - (\beta_1 + \beta_2)(Z_u - Z_l) \\ -\frac{\beta_3}{3}\left[(\alpha_1 - Z_u)^3 J_1 - (\alpha_1 - Z_l)^3 K_1\right] \\ -\frac{\beta_4}{3}\left[(\alpha_2 - Z_u)^3 J_2 - (\alpha_2 - Z_l)^3 K_2\right] \end{Bmatrix} \quad (2)$$

Where V is volume outside bark in ft³, k is π/576, H is total height in feet, Z_u is the ratio of upper bolt height to H, Z_l is the ratio of lower bolt height to H, and the α's and ß's are as previously defined. The J_i's and K_i's are indicator variables and are defined as:

$$J_i = \begin{cases} 1, \text{if } Z_u \le \alpha_i \\ 0, \text{if } Z_u \succ \alpha_i \end{cases}$$

$$K_i = \begin{cases} 1, \text{if } Z_l \le \alpha_i \\ 0, \text{if } Z_l \succ \alpha_i \end{cases}$$

Traditional development of compatible taper and volume functions involves parameter estimation for the taper function, which is then integrated to provide volume. This approach will minimize the error associated with stem diameter estimation but does not ensure minimal error in volume estimation. In an attempt to simultaneously minimize the error associated with taper and volume, Equation (1) and Equation (2) were simultaneously fit as seemingly unrelated regressions (SUR) using SAS/ETS Model Procedure (SAS Institute Inc. 1993).

RESULTS

Statistics of fit and parameter estimates from the SUR fitting procedure for Equation (1) and Equation (2) are presented in tables 3 and 4, respectively.

Taper

The proposed taper function was compared to the equation published by Baldwin and Polmer (1981) for planted longleaf in the West Gulf region. Residuals for diameter outside bark at several relative height classes were compared using statistics similar to those applied by Parresol and others (1987). These included: (1) the Sum of squared relative residuals (SSRR); (2) Mean absolute residual (AbsD); (3) Bias (D); and (4) Standard deviation of residuals (Sd) (table 5). The Baldwin and Polmer (1981) model was superior only in relative height class 1 (relative height of 0.06 to 0.15) and to a lesser extent, in relative height class 2 (table 6). The superiority in this part of the stem is due to the fact that for the tree sizes evaluated in this study, relative height class 1 reflects the relative height at dbh and the Bennett and others (1978) model employed by Baldwin and Polmer (1981) constrains the model to equal dbh at 4.5 feet. A review of the residual plot for the Baldwin and Polmer model indicated an over estimation of stem diameter at the base of the tree, an under estimation of stem diameter between relative heights of 0.2 and 0.5, and an over estimation of stem diameter between relative heights of 0.5 and 0.9. Both models are constrained to a 0 inch top diameter at total tree height. No irregularities were detected from the residual plot for the proposed model.

Volume

The proposed compatible cubic foot volume function was compared to the total cubic foot volume estimates from the Baldwin and Polmer (1981) and Baldwin and Saucier (1983) models using their published parameter estimates. In terms of total stem cubic foot volume (ob), the Baldwin and Polmer equation was superior to the Baldwin and Saucier equation and the proposed equation was superior to the Baldwin and Polmer equation. The same statistics used to evaluate the differences in stem diameter

Table 1—Description of sampled longleaf pine plantations

Plantation	Planting Spacing	Age	TPA	BA/AC	QMD (in)	DHT* (ft)
1	6*8	14	516	66.4	4.9	39.0
2	6*8	12	798	87.7	4.5	35.2
3	6*8	12	695	92.8	4.9	33.7

* Where DHT equals the average total height of dominant and codominant trees

Table 2—Distribution of felled longleaf pine sample trees by diameter and total height class

Dbh (in.)	20	25	30	35	40	Total
2	5	3				8
3		4	1			5
4		2	5	5		12
5			1	4	2	7
6				5	1	6
7				1	3	4
Total	5	9	7	15	6	42

Table 3—Nonlinear SUR summary of residual errors

Equation	DF Model	DF Error	SSE	MSE	R-Square	Adj R-Square
1	3	465	5.2521	0.0113	0.9579	0.9577
2	3	465	0.4426	0.000952	0.9684	0.9683

Table 4—Nonlinear SUR parameter estimates

Parameter	Estimate	Std Err	t value	P> |t|
B1	-3.0544	0.2902	-10.53	0.0001
B2	1.349745	0.1727	7.84	0.0001
B3	-1.36556	0.1662	-8.21	0.0001
B4	154.0197	22.8409	6.74	0.0001
A1	0.606008	0.0504	12.02	0.0001
A2	0.057371	0.00416	13.78	0.0001

Table 5—Statistics used to evaluate predicted diameters (ob) and total cubic foot volume (ob)

Sum of Squared Relative Residuals (SSRR)

$$\sum\left(\frac{y_i - \hat{y}_i}{y_i}\right)^2$$

Mean Absolute Residual (AbsD)

$$\frac{\sum ABS\left(y_i - \hat{y}_i\right)}{n}$$

Bias (D)

$$\frac{\sum\left(y_i - \hat{y}_i\right)}{n}$$

Standard Deviation of Residuals (Sd)

$$\left[\frac{\sum\left(y_i - \hat{y}_i\right)^2 - \frac{\left(\sum\left(y_i - \hat{y}_i\right)\right)^2}{n}}{n-1}\right]^{0.5}$$

Where: y_i represents either the observed diameter or volume (ob) and $\hat{y}_i$ represents either the predicted diameter or volume (ob).

estimates were applied to total cubic foot volume differences (table 7). The average residual (D) for the proposed model was 85 percent smaller than that for the Baldwin and Polmer equation. Differences between the standard deviation of the residuals were minute. A review of the residual plots indicated that the Baldwin and Saucier equation underestimated volume for all trees greater than 4 inches dbh. This bias increased directly with dbh with residuals ranging from –0.4 to 0.6 cubic foot. The Baldwin and Polmer equation underestimated volume for 78 percent of the trees with residuals ranging from –0.5 to 0.3 cubic foot. The proposed model was biased for trees in the 2 and 3 inch diameter class, however, this bias was small (< 0.1 cubic foot). Residuals ranged from –0.5 to 0.2 cubic foot.

Table 6—Statistics of fit for 10 relative height classes based on planted longleaf pine taper data

		Relative Height Class									
Model*	Statistic	0	1	2	3	4	5	6	7	8	9
1	SSRR	0.608	0.047	0.090	0.216	0.320	0.365	0.949	0.697	0.695	0.007
	AbsD	0.060	0.017	0.027	0.067	0.069	0.068	0.105	0.140	0.155	0.086
	D	-0.048	0.006	0.022	0.066	0.052	-0.007	-0.081	-0.132	-0.147	0.086
	Sd	0.339	0.101	0.122	0.168	0.231	0.287	0.330	0.228	0.207	
2	SSRR	0.313	0.084	0.071	0.058	0.131	0.230	0.518	0.257	0.234	0.002
	AbsD	0.043	0.026	0.031	0.031	0.043	0.050	0.080	0.072	0.085	0.039
	D	0.006	0.010	0.007	0.011	0.015	0.003	0.016	0.054	0.054	0.039
	Sd	0.249	0.136	0.128	0.156	0.188	0.236	0.275	0.175	0.177	

* (1) Baldwin & Polmer (2) Brooks and others

Table 7—Statistics to evaluate predicted total cubic foot volume for 42 longleaf pine trees

Statistics	Baldwin & Saucier (1983)	Baldwin & Polmer (1981)	Brooks and others
SSRR	0.46073	0.47951	0.36356
AbsD	0.12583	0.11511	0.09566
D	0.07009	0.06385	0.00984
Sd	0.16215	0.13627	0.13479

CONCLUSIONS

The objective of the study was to compare existing taper and cubic foot volume equations for planted longleaf pine in the West Gulf to an equation fit to 42 sample trees from plantations in southwest Georgia. It is not surprising that the proposed model had the smallest residuals since it was fit to the test data. How the existing equations predicted taper and/or volume compared to the proposed model was of primary interest. The Baldwin and Saucier (1983) volume equation possessed residual trends that would make it an unlikely candidate for use in these young plantations. The Baldwin and Polmer (1981) equations provided reasonable estimates of volume but was limited in its ability to accurately predict stem diameter. Further analysis is planned to fit the Bennett and others (1978) model and other nonlinear segmented polynomial models to this data set in an attempt to further reduce volume and taper estimation errors.

REFERENCES

Bailey, R.L. 1995. Upper stem volumes from stem analysis data:an overlapping bolts method. Canadian Journal of Forest Research. 25: 170-173.

Baldwin, V.C. Jr.; Polmer, B.H.; 1981. Taper functions for unthinned longleaf pine plantations on cutover West Gulf sites. In: Barnett, J.P., ed. Proceedings of the First biennial southern silvicultural research conference; 1980 November 6-7, Atlanta, GA. Gen. Tech. Rep. SO-34. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 156-163.

Baldwin, V.C.; Jr. Saucier, J.R. 1983. Above ground weight and volume of unthinned, planted longleaf pine on west gulf forest sites. Res. Pap.SO-191. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, 8p.

Bennett, F.A.; Lloyd, F.T.; Swindel, B.F.; E.W. Whitehorne. 1978. Yields of veneer and associated products from unthinned, old-field plantations of slash pine in the North Florida and South Georgia flatwoods. Res. Pap. SE-176. Ashville: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 80 p.

Max, T.A.; Burkhart, H.E. 1976. Segmented polynomial regression applied to taper equations. Forest Science. 22(3): 283-289.

Parresol, B.A.; Hotvedt, J.E.; Q.V. Cao. 1987. A volume and taper prediction system for bald cypress. Canadian Journal of Forest Research. 17: 250-259.

SAS Institute. 1993. SAS/ETS User's Guide, Version 6, Second Edition. SAS Institute, Inc. Cary, NC.

Wiant, H.V., Jr.; Wood, G.B.; G.M. Furnival. 1992. Estimated log volume using the centroid position. Forest Science. 38(1): 187-191.

ECONOMIC EVALUATION OF RESTORING THE SHORTLEAF PINE—BLUESTEM GRASS ECOSYSTEM ON THE OUACHITA NATIONAL FOREST

Michael M. Huebschmann, Daniel S. Tilley, Thomas B. Lynch, David K. Lewis, and James M. Guldin

POSTER SUMMARY

The USDA Forest Service is restoring pre-European settlement forest conditions on about 10 percent (155,000 acres) of the Ouachita National Forest in western Arkansas. These conditions — characterized by large, scattered shortleaf pine and hardwoods maintained on 120-year rotations, with bluestem grass and associated herbaceous vegetation in the understory — are expected to re-establish a broad habitat type missing from the landscape, one suited to supporting the recovery of the endangered red-cockaded woodpecker (USDA Forest Service 1996a, 1996b). This study was designed to forecast the amount of timber harvest volume and revenue the Ouachita National Forest may forego by adopting the shortleaf pine-bluestem grass (or pine-bluestem) management system in lieu of traditional, even-aged management.

Published growth and yield models were used to predict volumes available for harvest during a 100-year-long period in the pine-bluestem restoration area under both scenarios. Table 1 contrasts the rotation lengths and other significant characteristics of the two management scenarios. A model for predicting timber sale value was developed, and then applied to the predicted volumes in order to compare the respective revenue streams (Huebschmann 2000, Huebschmann and others 2000).

During the 100-year simulation period, the pine-bluestem scenario produces 26 percent less pine sawlog volume in the restoration area. Timber sale revenue from the area also declines by 51 percent in present-value terms. Because the pine-bluestem area covers only a small portion of the Ouachita National Forest, however, this decline translates into a Forest-wide revenue reduction of between 2 and 5 percent.

As a result of restoring the pine-bluestem ecosystem, the Forest Service expects to provide habitat capable of eventually supporting 400 breeding pairs of red-cockaded woodpeckers. By foregoing the revenue that could be generated under even-aged management, the Forest Service places an implicit value of about $1,700 per year (in present-value terms) on each woodpecker.

Table 1—Characteristics of the traditional even-aged and pine-bluestem management scenarios compared in this study

	Management scenario	
Characteristic	Traditional	Pine-Bluestem
Rotation length (yr)	80	120
Stand BA (ft²/ac)	60≤pine≤90 10≤hdwd≤15	60≤pine≤80 10≤hdwd≤15
Post-harvest residual overstory BA (ft²/ac)	20 pine 10 hdwd	40 pine 10 hdwd
Burning interval (yr)	4	3

The pine-bluestem management regime requires successful silvicultural treatments and growth and yield forecasts outside the range of general experience in the region. Thus, additional monitoring will be needed to validate the conditions and estimates used in this analysis.

REFERENCES

Huebschmann, M.M. 2000. Restoring the shortleaf pine-bluestem grass ecosystem on the Ouachita National Forest: An economic evaluation. Ph.D. dissertation. Oklahoma State Univ. Stillwater, OK. 141 p.

Huebschmann, M.M.; T.B. Lynch; D.K. Lewis. 2000. Restoring the shortleaf pine-bluestem grass ecosystem on the Ouachita National Forest: An economic evaluation. Final project report to the USDA Forest Service - Southern Research Station. 51 p.

[1]Natural Resource Economist, Boise Cascade Corporation, Boise, ID 83728; Professor, Dept. of Agricultural Economics, and Associate Professors, Dept. of Forestry, Oklahoma State University, Stillwater, OK 74078; Project Leader/Research Forest Ecologist, USDA Forest Service, Southern Research Station, Hot Springs, AR 71902, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

USDA Forest Service. 1996a. Renewal of the shortleaf pine/ bluestem grass ecosystem and recovery of the red-cockaded woodpecker: Final environmental impact statement for an amendment to the land and resource management plan, Ouachita National Forest. 94 p.

USDA Forest Service. 1996b. Record of decision: Final environmental impact statement. Amendment 22: Renewal of the shortleaf pine/bluestem grass ecosystem and recovery of the red-cockaded woodpecker. Ouachita National Forest land and resource management plan, Scott and Polk counties, Arkansas. USDA For. Serv. - Southern Region. 13 p.

ESTIMATING THE PROBABILITY OF ACHIEVING SHORTLEAF PINE REGENERATION AT VARIABLE SPECIFIED LEVELS

Thomas B. Lynch, Jean Nkouka, Michael M. Huebschmann, and James M. Guldin[1]

POSTER SUMMARY

A model was developed that can be used to estimate the probability of achieving regeneration at a variety of specified stem density levels. The model was fitted to shortleaf pine (*Pinus echinata* Mill.) regeneration data, and can be used to estimate the probability of achieving desired levels of regeneration between 300 and 700 stems per acre 9-10 years after thinning to a specified level of overstory basal area per acre. The level of regeneration to be achieved was used to modify a logistic model to estimate probability of obtaining regeneration at the desired level. Variables used in the model to predict probability of achieving the desired regeneration level were site index for shortleaf pine (base age 50), overstory basal area, age at time of thinning and a dummy (0 or 1) variable representing year of plot establishment.

The data consisted of measurements made on 5-milacre plots located within 182 circular permanent plots, 0.2-acre in size. These plots were established in natural even-aged pure shortleaf pine stands thinned to predetermined residual overstory basal area levels in one of four density categories: 30, 60, 90 or 120 square feet per acre. Plots were established in four age categories (20, 40, 60 and 80 years) and in four site index classes (50, 60, 70, 80 feet at 50 years). At the time of plot establishment hardwoods were treated with herbicide by tree injection or girdling. Each 0.2-acre plot was surrounded by a 33-foot buffer strip, which received the same thinning and herbicide treatment. Shortleaf pine regeneration stems were tallied on two 5-milacre plots located due north and south midway between the plot center and the boundary of each 0.2-acre shortleaf pine overstory plot. The regeneration sample occurred 9-10 years after plot establishment.

Larson and others (1997) used a logistic model to predict the probability of achieving specified levels of oak regeneration. Target density levels could not be varied within a particular equation for the models developed by Larson and others (1997). However, they fitted several equations independently to different target density levels. For the current study, varying levels of shortleaf pine regeneration density levels were obtained by using the natural logarithm of the specified density level as an independent variable in a logistic model. To obtain a satisfactory fit for the model it was necessary to form an independent variable by multiplying the natural logarithm of density level by the square of site index.

Parameter estimation for this model with common logistic regression software is problematic because the level of regeneration success is variable. Therefore, a maximum likelihood procedure was developed and used to estimate parameters in this model. Three levels of regeneration success were specified for the purpose of parameter estimation: 300, 500 and 700 stems per acre. These levels were used to define regeneration categories such that each plot could be assigned to one of these categories, for example, more than 300 but less than 500 stems per acre. A multinomial distribution based on these categories was used to develop a likelihood function. The modified logistic function was used to represent probabilities in the likelihood function. The LOGDEN function in SHAZAM (White 1993) econometric software was used to maximize the likelihood function with respect to equation parameters so that maximum likelihood estimates were obtained.

Parameter estimates from the model indicate that adequate shortleaf pine regeneration is less likely on good sites than on poor sites as measured by shortleaf pine site index. Adequate shortleaf pine regeneration becomes less likely as overstory basal area per acre increases, and is less likely at young overstory stand ages. The parameter estimate associated with year of thinning and herbicide treatment indicates that the probability of obtaining adequate regeneration can vary substantially due to the year in which thinning and herbicide treatment occurred. This could be due to variability in shortleaf pine seed crops and/ or conditions for seedling establishment and survival. The resulting model for prediction of probability for regeneration success should be applicable for levels of shortleaf pine regeneration between 300 and 700 stems per acre.

---

[1]Associate Professor and former Graduate Research Assistant, Department of Forestry, Oklahoma State University, Stillwater, OK 74078-6013; Natural Resource Economist, Boise Cascade Corporation, P.O. Box 50, Boise, ID 83728-0001; Project Leader/Research Forest Ecologist, USDA Forest Service Southern Research Station, Monticello, AR 71656-3516, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

REFERENCES

Larson, D.R.; Metzger, M.A.; Johnson, P.S. 1997. Oak regeneration and overstory density in the Missouri Ozarks. Canadian Journal of Forest Research. 27: 869-875.

White, K.J. 1993. SHAZAM user's reference manual version 7.0 - second printing. New York: McGraw-Hill. 482 p.

Understory

Moderator:

KEN OUTCALT
USDA Forest Service

PRELIMINARY RESULTS: EFFECTS OF FERTILIZATION, HERBICIDE APPLICATION, AND PRESCRIBED BURNING ON UNDERSTORY REGENERATION ON PINE PLANTATIONS IN EAST TEXAS

Betsy Ott, Brian Oswald, Hans Williams, and Kenneth Farrish[1]

Abstract —Biodiversity and species rareness are increasingly the focal points for assessment of habitat quality. Managed pine plantations are often viewed as monocultures with little of value beyond their timber crop. The purpose of this study is to assess vegetative biodiversity in the understory of two pine plantations in which different vegetative control mechanisms are being evaluated. Controlled burn, herbicide treatment, and a combination of both are being compared on fertilized and unfertilized plots on two loblolly pine (*Pinus taeda*) plantations in east Texas. This study will compare species diversity and frequency on untreated and treated plots. One-square meter quadrat samples will be evaluated from 0.04 ha sampling plots within 0.1 ha treatment plots. Species richness will be determined as the number of species in each treatment plot. Shannon Index of Heterogeneity will be determined for each treatment. Comparison of different treatments will be made based on species richness and the Shannon diversity indices. Results for the first growth season after treatment will be presented.

INTRODUCTION

Preserving biodiversity has increasingly been recognized as an important management objective in both natural and planted stands (Carey and Curtis 1996; Franklin 1988, Hansen and others 1991; Roberts and Gilliam 1995). The Society of American Foresters recommends management of forestlands to "conserve, maintain, or enhance" biological diversity (SAF, 1991). Maintenance of biodiversity is a value often attributed to good forestry practice, at least on public lands.

Private land owners may become increasingly sensitive to the impact of silvicultural treatment on understory biodiversity as a consequence of increased public attention focused on this value. Limited studies have shown understory biodiversity in managed plantations to be comparable in some cases to that found in naturally reforested areas (Graee & Heskjaer 1997); other studies have shown reduced biodiversity (Hansen and others 1991). It is intuitively obvious that understory diversity will increase when deforested areas are planted in trees, even if the overstory is a monoculture (Lust and others 1998). Comparison of pine plantations to deforested areas would likely show greater biodiversity in the plantations. Further, the plasticity of crop trees such as *Pinus taeda* allows establishment on a variety of sites, which will show major differences in understory communities even though the overstory is homogeneous. Adding to the potential variability is the variation in canopy cover due to management processes such as thinning. In comparison to an undisturbed forest stand, a planted stand after row thinning can have considerably more light reaching the understory, creating more heterogeneity on the forest floor. Other management strategies could also affect understory biodiversity. Pine plantations thus are a potentially valuable natural resource in terms of vegetative biodiversity in the understory species.

This study was undertaken to determine the effect of treatments applied for the crop trees on the understory species richness, species diversity, and ground cover, as measures of biodiversity. Treatments included fertilization, prescribed burning, and herbicide application. The effect of applying herbicide was not analyzed after the first year.

MATERIALS AND METHODS

Field Setup

Two sites were selected in Cherokee County south of Alto, Texas, based on similarities in time of planting and thinning of loblolly pines. On each site, five replicates were established. Within each replicate, eight 0.10 ha treatments plots were set up with ten-meat buffer strips between treatment plots. Nested at the center of each treatment plot is a 0.04 ha measurement subplot.

[1]Ph.D. candidate, Associate Professors, Arthur Temple College of Forestry, Stephen F. Austin State University, Nacogdoches, Texas, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

TABLE 1— Species Lists for Cherokee Ridge and Sweet Union

Common Name	Scientific Name	Site(s)
FERNS		
royal fern	*Osmundia regalis*	CR
cinnamon fern	*Osmundia cinnamomea*	CR
brackenfern	*Pteridium aquilinum*	CR
FORBS		
common ragweed	*Ambrosia artemisifolia*	CR,SU
flowering spurge	*Euphorbia pubentissima*	CR,SU
yellow wood sorrel	*Oxalis stricta*	CR,SU
butterfly pea	*Centrosema virginianum*	CR,SU
black snakeroot	*Sanicula Canadensis*	CR
croton (goatweed)	*Croton capitatus*	CR
dewberry	*Rubus* spp.	SU
blackberry	*Rubus argutus*	CR,SU
dogfennell (cypressweed)	*Eupatorium capillifolium*	CR,SU
late boneset	*Eupatorium serotina*	CR,SU
selfheal	*Prunella vulgaris*	CR,SU
fleabane	*Erigeron strigosus*	CR,SU
partridge pea	*Chamaecrista fasciculate*	CR,SU
lyreleaf sage	*Salvia lyrata*	CR
American black nightshade	*Solanum americanum*	CR
butterfly milkweed	*Asclepias tuberosa*	CR
wild onion	*Allium canadense*	CR
skullcap	*Scutellaria integrifolia*	CR
bitter sneezeweed	*Helenium amarum*	SU
elephant's foot	*Elephantopus tomentosus*	SU
geranium	*Geranium carolinianum*	SU
horse nettle	*Solanum carolinense*	SU
tropic croton	*Croton glandulosos* var. *septentrionalis*	SU
Sub-shrubs		
green wild indigo	*Baptisia sphaerocarpa*	CR,SU
St.Andrew's cross	*Hypericum hypericoides*	SU
Common Shrubs		
American beauty berry	*Callicarpa Americana*	CR, SU
southern wax myrtle	*Myrica cerifera*	CR
plainleaf sumac	*Rhus copallinum*	CR,SU
eastern bacchcaris	*Baccharis halimifolia*	CR
devil's-walkingstick	*Aralia spinosa*	CR
Small Trees		
yaupon	*Ilex vomitoria*	CR,SU
winged elm	*Ulmus alata*	CR,SU

TABLE 1, continued— Species Lists for Cherokee Ridge and Sweet Union

Common Name	Scientific Name	Site(s)
American holly	*Ilex opaca*	CR,SU
tree sparkleberry	*Vaccinium arboreum*	CR,SU
rusty blackhaw	*Viburnum rufidulum*	CR,SU
eastern redcedar	*Juniperus virginiana*	CR,SU
sweet bay magnolia	*Magnolia virginiana*	CR,SU
sassafras	*Sassafras albidum*	CR
persimmon	*Diospyros virginiana*	CR
parsley hawthorn	*Crataegus marshallii*	SU
flowering dogwood	*Cornus florida*	SU
Canopy Trees		
sweet gum	*Liquidambar styraciflua*	CR, SU
water oak	*Quercus nigra*	CR, SU
post oak	*Quercus stellata*	CR
blackjack oak	*Quercus marilandica*	CR
black gum	*Nyssa aquatica*	CR
willow oak	*Quercus phellos*	CR
mockernut hickory	*Carya tomentosa*	CR
southern red oak	*Quercus falcate*	SU
white oak	*Quercus alba*	SU
willow oak	*Quercus phellos*	SU
Vines		
poison ivy	*Toxicodendron radicans*	CR,SU
greenbriar	*Smilax* spp	CR,SU
Virginia creeper	*Parthenocissus quinquefolia*	CR,SU
mustang grape	*Vitis rotundifolia*	CR,SU
peppervine	*Ampelopsis arborea*	CR,SU
Alabama supplejack	*Berchemia scandens*	CR,SU
trumpetcreeper	*Campsis radicans*	CR
clematis	*Clematis* sp.	CR

At the site referred to as Cherokee Ridge, a total of 78 hectares were planted in 1985 and row-thinned to a BA of 13.1 m2 ha -1 in 1998. At the outset of the study, soils were classified as Darco, Teneha, and Osier. The topography of the research area is relatively flat upland with mild slopes.

At the site referred to as Sweet Union, 45 hectares were planted in 1982 and row-thinned to a BA of ~ 22.3 m^2/ha in 1998. Soils were classified as Attoyac and Ruston. The topography is similar to the Cherokee Ridge site.

Vegetation Surveys

Four random quadrats within each treatment block were inventoried in April or May, 1999 and again in June or July, 1999. Ground coverage was recorded by class (trace; 1 – 5 percent; 6 – 10 percent;11- 20 percent; 21 – 50 percent; 51 – 75 percent; 76 – 95 percent; 96 – 100 percent) for each vegetation class (species or genus for herbaceous and woody dicots; collectively for graminoids), and number of individuals was recorded for each species of forb, sub-shrub, shrub, vines, small tree, and canopy tree. An individual could be a single stem, a bunch, or a cluster, depending on growth form. Flowering specimens were collected for taxonomic identification. Additional data recorded but not analyzed for this paper includes litter and coarse woody debris (percent coverage using the same classification as ground cover) and percent canopy cover directly over each sampling quadrat. A species list was compiled for each site.

Identical surveys on random quadrats were conducted in late May – early June, 2000. Severe drought precluded sampling in July; most plots showed little growth and most forbs were wilting and dying in July.

Treatments

Herbicide was applied in October, 1999. Accord and Chopper tank mix was applied with a backpack sprayer. At Cherokee Ridge, the mix consisted of 4.5 L Chopper and 2.2 L Accord suspended in 11.2 L Sun-it oil with 76.7 L water per Ha. At Sweet Union, the amount of Accord was increased to 2.5 L. Larger trees were treated with 100 ml of Arsenal AC in 300 ml of water using the “hack-n-squirt” method.

The prescribed burn was conducted during March, 2000 after installing firelines the previous winter. Backfires prevented the spread into most buffer zones, or at least into the next treatment plot. Fertilizer was applied in April, 2000. Urea was applied at a rate of 224 kg/ha N and Diammonium Phosphate (DAP)at a rate of 28 kg/ha P.

Statistical Analysis

Statistical comparisons were conducted using The SAS System (version 8 for Windows). Analysis of variance was determined using General Linear Model Analysis (alpha level of 0.1) to evaluate any changes in species richness or homogeneity, or percent ground cover due to treatments as well as species-specific responses to treatments. Comparisons were based on measures of species richness (number of species per treatment plot, combined for all four sample quadrats per plot), species diversity (using the Shannon index), and percent ground cover classification recorded for each taxon in each quadrat.

Pre-treatment Analysis

Comparisons between sites and between treatment plots were made to determine between-site and within-site homogeneity.

Post-treatment Analysis

Post-treatment analysis consisted of comparing fertilized to unfertilized plots, and burned to unburned plots, as well as looking for interaction between these two treatments. Additionally, comparison between 1999 data and 2000 data were made on each plot. Effects of herbicide were not analyzed after the first year, as most plots with herbicide applied showed little understory growth in the summer after treatment.

Response to treatment of specific species was also analyzed. Frequent species were selected for analysis, including American beauty berry(*Callicarpa americana*), late boneset(*Eupatorium serotina*), poison ivy (*Toxicodendron radicans*), and yellow wood sorrel(*Oxalis stricta*). These species were selected due to their ubiquity at both sites, in many of the plots analyzed, compared to the other species on the list (nearly 100 in all).

RESULTS

Pre-Treatment Site Comparisons

No significant differences were found in either pre-treatment species richness ($P = 0.1026$) or species diversity ($P = 0.1142$) between the two sites.

Species lists for both sites are shown in table 1. While species-specific variability between and within sites clearly exists, no analytic examination of these differences was carried out at this point.

Pre-Treatment Plot Comparisons

No significant differences were found in pre-treatment species richness or species diversity for eight of the ten plots. Plots designated 1 and 3 at Cherokee Ridge had significantly lower species richness ($P < 0.0001$) and species diversity ($P = 0.0003$) than all other plots. These two plots bordered the stream bed; the lowest subplots were significantly wetter in the spring than all the other subplots and had a greater percent of coverage by grass, with fewer trees. The subplots above the bottom had greater slope than all other plots. Significant drought over the last three years could have had a greater impact on these two plots than all the others. Specific values for species diversity and species richness are shown in table 2.

Post-treatment Analysis

No significant difference was found ($P = 0.53$) in total number of individuals per species per plot, species richness, or species diversity, between treatments. A significant reduction in percent ground cover class was identified in plots treated with prescribed burning but not fertilized ($P < 0.0001$). No significant difference was found

Table 2—Species Richness and Shannon Diversity Indices of Pretreatment Plots

Plot	Species Richness	Shannon Index
CR-5	15.375	0.99652
SU-5	15.250	0.89729
SU-2	12.500	0.89382
CR-2	12.625	0.88817
CR-4	13.375	0.86574
SU-1	11.000	0.86515
SU-4	10.250	0.85264
SU-3	9.875	0.80688
CR-3	6.000*	0.68288**
CR-1	6.000*	0.63308**

*indicates significantly different values ($P < 0.0001$).
**indicates significantly different values ($P = 0.0003$).

in the number of individuals, between treatments, for the five selected species.

CONCLUSIONS

Change in Measures of Biodiversity

Species richness and species diversity in understory vegetation appear, on the basis of these preliminary results, to be unaffected by the treatments applied to increase growth in the planted pine overstory.

Response of Ground Cover

There is a significantly lower percent ground cover on plots that were not fertilized after burning, compared to plots that were fertilized after burning and compared to unburned plots, with or without fertilizer. Fertilizer alone did not significantly increase percent ground cover, nor did the prescribed burn significantly alter percent ground cover on fertilized plots. Only on unfertilized plots did the prescribed burn reduce percent ground cover in the same year as the burn.

Based on these first-year results, foresters could predict that treating plots with prescribed burning alone can reduce understory ground cover in the following growing season, while treating plots with fertilizer alone will not affect ground cover, and applying fertilizer to burned plots can offset the effect of burning on ground cover.

ACKNOWLEDGMENTS

The authors would like to acknowledge Dr. Jimmie Yieser for his assistance in herbicide application. Funding was provided by the Forest Resources Institute(FRI) of the Arthur Temple College Of Forestry. The assistance of FRI staff member Jay Tate, graduate students Michelle Barnett, Shea Wilson, Lisa Marino, Richard Ott, and Bret Gentzler, and many undergraduate students is gratefully acknowledged.

REFERENCES

Carey, Andrew B; Curtis, Robert O. 1996. Conservation of biodiversity: a useful paradigm for forest ecosystem management. Wildlife Society Bulletin. 24(4): 610-620.

Franklin, J.F. 1988. Structural and functional diversity in temperate forests. In: Wilson, E.O., ed. Biodiversity. Washington, D.C.: National Academy of Sciences Press: 166-175.

Graae, B. J.; Heskjaer, V.S. 1997. A comparison of understorey vegetation between untouched and managed deciduous forest in Denmark. Forest Ecology and Management. 96: 111-124.

Hansen, A. J.; Spies, T. A.; Swanson, F. J. 1991. Conserving biodiversity in managed forests: lessons from natural forests. BioScience. 41: 382-392.

Lust, N.; Muys, B.; Nachtergale, L. 1998. Increase of biodiversity in homogeneous Scots pine stands by an ecologically diversified management. Biodiversity and Conservation. 7(2): 249-260.

Roberts, M.R.; Gilliam, F.S. 1995. Patterns and mechanisms of plant diversity in forested ecosystems: implications for forest management. Ecological Applications. 5(4): 969-977.

Society of American Foresters. 1991. Biological diversity in forest ecosystems. Journal of Forestry. 90: 42-43.

STRUCTURE AND COMPOSITION OF VEGETATION OF LONGLEAF PINE PLANTATIONS COMPARED TO NATURAL STANDS OCCURRING ALONG AN ENVIRONMENTAL GRADIENT AT THE SAVANNAH RIVER SITE

Gregory P. Smith, Victor B. Shelburne, and Joan L. Walker[1]

Abstract—Fifty-four plots in 33-43 year old longleaf pine plantations were compared to 30 remnant plots in longleaf stands on the Savannah River Site in South Carolina. Within these stands, the structure and composition of primarily the herb layer relative to a presumed soil moisture or soil texture gradient was studied using the North Carolina Vegetation Survey methodology. Data were also collected on soils and landform variables. Based on ordination and cluster analyses, both plantation plots and natural stand plots were separated into three distinct site units (xeric, sub-xeric, and sub-mesic). The plantation plots had an overall classification rate of 78 percent while the natural plot classification rate was 87 percent. The xeric end of the gradient demonstrated the most similarity between the remnant and plantation plots. Among all the plots, presence or absence of a B horizon was the most discriminating environmental factor. On the plantation sites, 265 species were found as compared to 297 species on the remnant natural sites. Overall species richness was significantly greater on the remnant sites with a mean of 74.00 species per 0.1 hectare compared to 57.11 for the plantation sites. However, of the 265 species found on plantation sites, roughly 90 percent were judged to be representative of natural or native longleaf pine communities. This lack of a major compositional difference between xeric plantation and natural longleaf sites suggests that restoration of the herbaceous layer may not be as complex as once thought. This provides reasonable encouragement for the restoration of the longleaf pine ecosystem.

INTRODUCTION

The decline of the longleaf pine ecosystem has been well documented. Longleaf pine once dominated as much as 92 million acres throughout the Southeastern United States (Frost 1993). This natural range covered most of the Atlantic and Gulf Coastal Plain regions, from southeastern Virginia to eastern Texas and south into the northern two-thirds of Florida, with extensions into the Piedmont and mountains of northern Alabama and northwest Georgia (Landers and others 1995). Recent estimates show that there may be as little as 3.2 million acres of natural longleaf pine left (USDA Forest Service, Forest Inventory and Analysis, unpubl. data). For this reason, there has been an increase in the efforts to sustain the natural longleaf stands that remain and to restore these ecosystems on a portion of the sites from which they have been extirpated (Mitchell and others 1997).

There is a growing interest in the structure and composition of pine plantations and how they compare to natural longleaf stands. This information is needed to assess the potential for restoration and to develop protocols for restoration. Information about the distribution of longleaf pine communities along environmental gradients (e.g. Christensen 1988, Harcombe and others 1993, Peet and Allard 1993, Jones and others 1984) is available, but little has been published regarding the composition and structure of plantations relative to the same environmental gradients.

This study describes current vegetation patterns and relationships on disturbed plantation sites and compares them to natural, or relatively undisturbed, longleaf pine stands at the Savannah River Site. Sample sites were mostly pine dominated upland sites. Keeping in mind that the ultimate management goal of these plantation sites is restoration to their "natural" state, an understanding of the historical/natural ecosystem conditions, current conditions, and processes that affected the changes is required (Walker and Boyer 1993).

STUDY AREA

The Savannah River Site (SRS) is a 192,323-acre circular tract of federal land that occupies parts of Aiken, Barnwell, and Allendale Counties, South Carolina (Cooke 1936). It is located northeast of the Savannah River on the upper Atlantic Coastal Plain of South Carolina. The Savannah River Site (SRS) has three major geologic/ physiographic regions. These regions are the sandier, excessively drained and droughty areas called the Sandhills Region, the more productive sandy loams and loamy soils of the Upper Loam Hills Region, and the more fertile, well-drained soils of the Red Hills Region (Myers and others 1986). Present vegetation at the SRS largely reflects past disturbance or manipulation by man and is distributed across a moisture gradient extending from xeric, droughty, deep sandy ridges to hydric,

[1] Graduate Research Assistant, Associate Professor, Department of Forest Resources, Clemson University, Clemson, SC 29634; Research Ecologist, USDA Forest Service, Southern Research Station, Clemson, SC 29634, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

flooded marshes and swamps (Jones and others 1981, Van Lear and Jones 1987). These disturbed sites are old fields that were the result of intensive agriculture and subsequently replanted with pine, less intensive agricultural sites that were left to regenerate naturally, cutover forests that have had a continuous forest cover of scrub oak/pine, and areas where the natural fire regime has been altered or suppressed.

METHODS

Site Selection

Fifty-four plantation sites were selected at the SRS by using a predetermined set of criteria. Sites must have been (1) dominated by longleaf or slash pine only, (2) planted between 1955 and 1965, (3) located on one of three different soil moisture classes, and (4) burned at least once within the past five years. This method of site selection was accomplished through the use of Geographical Information System (GIS) ARC/INFO software from the Savannah River Forest Service-GIS laboratory. Because too few longleaf pine plantations were available, slash pine plantations on sites originally dominated by longleaf pine were incorporated into this study to increase the sampling area. Because prior history and site preparation methods were similar, consistency between slash and longleaf ground vegetation was expected.

Thirty natural longleaf pine stands were located at the SRS using a variety of methods. First, candidate stands were identified in an inventory by Cecil Frost, Plant Ecologist, North Carolina Department of Agriculture. Additional plots were located using information from local botanists, ecologists, United States Forest Service personnel, GIS software, satellite imagery, digitized maps linked to databases, and reconnaissance work in the field to locate other suitable natural stands. Criteria used to help determine natural vegetation included, but were not limited to (1) observations of vegetation structure, by layer, under known fire regimes, (2) presence of remnant fire frequency indicator species, (3) presence of remnant fire frequency indicator communities, and (4) known historical records of remnant or natural areas (Frost 1997).

Field Sampling

Plot size for most North Carolina Vegetation Survey (NCVS) plots was 20 x 50 meters (1000m^2 or 0.1 hectare). An alternative configuration of 20 x 20 meter (400m^2) plots was used for sampling several of the natural longleaf stands. This alternative plot size was necessary due to the relatively small patches of natural longleaf pine scattered throughout the Savannah River Site. Using a smaller plot size (400m^2) was the only method available to ensure homogenous sampling of natural vegetation. This alternative plot size (400m^2) is within the size range recommended by Mueller-Dombois and Ellenberg (1974) for sampling forest vegetation. The widespread use of these NCVS plots in a variety of forested vegetation types and the consequent availability of substantial comparative vegetation data at this scale led to the adoption of these plot sizes.

The NCVS (Peet and others 1998) uses a modular approach for sampling. Within each 0.1 ha (1000 m^2) plot, there was a 2 x 5 array of 10 x 10m modules (100 m^2 or 0.01 hectare). Within this 2 x 5 array of modules, there was a prescribed block of four focal modules (in a 2 x 2 array). The focal modules were intensively sampled. An aggregate count of woody stems was made in the remaining six modules, and this area (600 m^2) was searched for species not encountered in the four focal modules measured previously. In the alternative configuration of 400m^2 plots, all four modules were treated as focal modules and intensively sampled according to NCVS methodology.

Soil samples for chemical analysis were collected in the center of each of the focal. For each sample a core of mineral soil to a depth of 10 cm was collected for chemical analysis. Soil samples for textural analysis were collected in the middle of the plot along the midline. A sample of the A and B or C horizon was collected and depth to maximum clay and depth of litter layer recorded. The soil series and a description of the soil profile were also recorded. Soil samples were analyzed by Brookside Labs (308 S. Main St., Knoxville, OH 45781).

Data Analysis

A series of multivariate techniques was used for data analysis. Detrended Correspondence Analysis (DCA) (DECORANA, Hill 1979a), was on used to analyze vegetation data (McCune and Mefford 1999). DCA or DECORANA© is an ordination program that ultimately displays stand and/or species data in multidimensional space (Hill 1979a). The distance between stands or species indicates the relative degree of similarity or difference (Hutto and others 1999).

Cluster analysis of vegetation was performed by Two Way Indicator Species Analysis (TWINSPAN, Hill 1979b). TWINSPAN© is a polythetic diverse classification that simultaneously classifies both species and plots using the main matrix for vegetation data (McCune and Mefford 1999). TWINSPAN was used in conjunction with DCA to reduce this subjectivity in delineating groups of similar plots. TWINSPAN was also used to identify indicator or diagnostic species that were strongly correlated to a certain community association.

Stepwise discriminant analysis and discriminant analysis techniques were used to identify those environmental variables which best described the stands which had already been placed into groups by ordination and classification(Afifi and Clark 1990). Soil and landform variables were used in the analysis. Stepwise discriminant analysis was used to determine which of these variables were significant at the 0.15 and 0.20 level of significance for plantations and natural sites respectively. Discriminant analysis was then used to accurately predict site unit membership using the discriminating environmental variables that were identified for both plantation and natural stands.

Standardized t-tests at the 0.05 level of significance were used to test for significant differences between plantations and natural stands. Mean environmental and physical

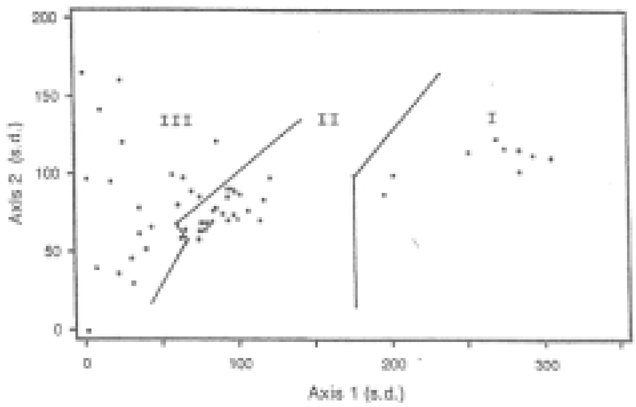


Figure 1—Ordination of 54 plantation plots using full importance values.

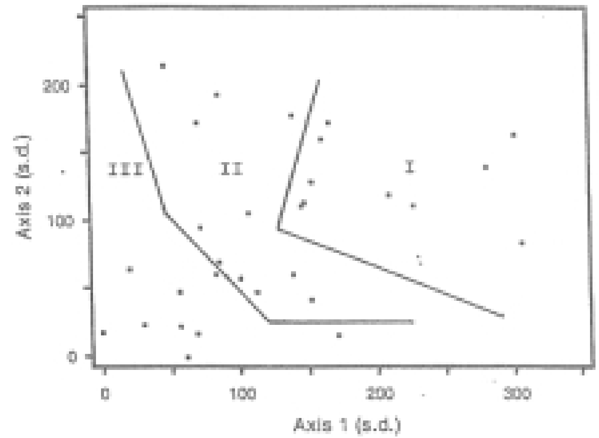


Figure 2—Ordination of 30 natural plots using full importance values.

variables as well as species abundances were tested for significant differences between plantation and natural sites occurring on similar soil moistures.

RESULTS

Plantation Sites

The primary data matrix for plantation sites consisted of 54 plots and 265 species. The ordination Axis 1 was related to a soil moisture gradient (figure 1). Based on ordination and cluster analysis, the plots were separated into three groups. Plots near the origin of the graph exist on the extreme xeric end of the soil moisture gradient, while plots near the end of the graph exist on the more mesic end of the gradient. Groups were labeled I, II, and III, with I on the mesic and III on the xeric end of the gradient. There was also some variation among plots on the xeric end of Axis 2. The source of this variation has not been determined, and is most likely the result of some disturbance due to previous land use.

Of the fifteen environmental variables used in stepwise discriminant analysis, three significant variables were found at the 0.15 level of significance for plantations. These variables were (1) presence/absence of B horizon, (2) soil pH, and (3) percent sand in B or C horizon.

Discriminant function analysis determined the classification success rate for each ecological site unit or group. The resubstitution success rate was 81 percent and misclassified a total of eight plots. The cross-validation success rate was 78 percent and misclassified nine plots.

TWINSPAN was used to find indicator species for each group of plantation sites identified. Generally, an indicator species is a species of narrow ecological amplitude with respect to one or more environmental factors (Allaby 1994). For this study, indicator species are defined more loosely as the most characteristic community members and include species typical of and vigorous in a particular environment. Indicator species for group I sites included *Pinus elliottii*, *Pinus taeda*, and *Chimaphila maculata*. Indicators of group II sites included *Dichanthelium commutatum*, *Desmodium vridiflorum*, and *Centrosema virginianum*. *Quercus laevis*, *Quercus incana*, and *Bonamia patens* were indicators of group III sites.

Natural Stands

The primary data matrix for natural stands consisted of 30 plots and 297 species. Ordination arranged these plots along a soil moisture gradient (axis 1) that showed a beta diversity of 3.5 standard deviations (figure 2). Based on ordination and cluster analysis, these plots were separated into three groups, with plots (group III) near the origin of the graph on the extreme xeric end of the gradient, and plots (group I) near the end of the graph on the more mesic end of the gradient. Axis 2 showed a beta diversity of 2.5 standard deviations.

Of the fifteen environmental variables used in discriminant analysis, eleven were found to be significant at the 0.20 level of significance. These variables were (1) presence/absence of B horizon, (2) landform index, (3) soil magnesium, (4) sodium, (5) calcium, (6) nitrogen, and (7) potassium, (8) organic matter, (9) percent sand in respective horizon, (10) percent clay in the respective horizon, and (11) percent sand in the A horizon.

Discriminant function analysis was then performed to find classification success rates for each ecological site unit or group. The resubstitution success rate was 100 percent. The cross-validation success rate was 87 percent with four plots missclassified.

Each group of natural stands defined by ordination/classification revealed a distinguishable group of vegetation and set of associated physical and environmental variables. TWINSPAN was used to find indicator species for each group of natural stands identified. Iindicators of group I sites include *Quercus stellata*, *Aristolochia serpentaria*, and *Clitoria mariana*. Group II indicators included *Aristida beyrechiana* and *Pinus taeda*. *Opuntia compressa*, *Cnidoscolus stimulosus*, and *Cirsium repandum* were indicators of group III sites.

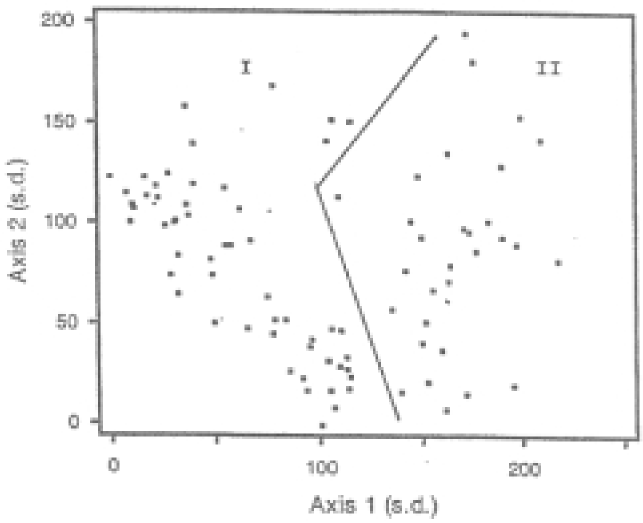


Figure 3—Initial ordination of both plantation and natural plots (n = 84) using species presence/absence values and first order division.

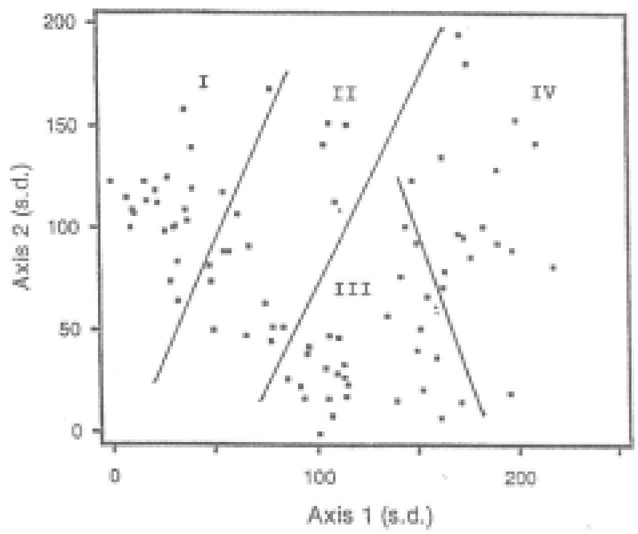


Figure 4—Ordination of both plantation and natural plots (n = 84) using species presence/absence values and second order division.

Plantation Sites Versus Natural Stands

The primary data matrix for both plantations and natural stands consisted of 84 plots and 361 species. Ordination separated all eighty-four plots into two groups (figure 3). These groups corresponded to the first order division of TWINSPAN. Plots were separated into two distinct associations based on origin (plantation or natural). Ordination arranged each of these groups along a distinct soil moisture gradient (axis 1) that showed an overall beta diversity of 2.5 standard deviations. Group I plots were identified as plantation sites and arranged along a soil moisture gradient that has a beta diversity of 1.5 standard deviations. Plots near the origin of the graph exist on the mesic end of the soil moisture gradient, while plots near the center of the graph exist on the xeric end of the gradient. Group II plots were identified as natural stands and arranged along a soil moisture gradient that showed a beta diversity of 1.0 standard deviations. Plots near the center of the graph exist on the xeric end of the soil moisture gradient, while plots near the end exist on the mesic end of the gradient.

The second order of division of TWINSPAN was used to further break down plot groupings. Plots were then separated into four groups (figure 4). These groups exist along the same presumed soil moisture gradients noted above. Groups were labeled I, II, III, and IV. Of the four groups identified, groups I and II were of plantation origin and IV was of natural origin. Group III was the only group of plots that displayed combination of plantation and natural stands (figure 5). Group III occurred on the xeric end of the soil moisture gradient. This would suggest that on the most xeric sites, similar vegetation may exist on both plantation and natural stands. Group III was further divided by the third order of division. Group III_A identifies plots of plantation origin while group III_B identifies plots of natural origin.

Overall mean species richness of plantation sites ranged from a low of 53.44 species per 0.1 hectare on sub-mesic sites to a high of 60.73 species per 0.1 hectare on sub-xeric sites. Overall mean species richness of natural sites ranged from a low of 71.09 species per 0.1 hectare on sub-xeric sites to a high of 76.33 species per 0.1 hectare on xeric sites. The species richness across all natural stands was found to be significantly higher compared to plantations (74.00 versus 57.11 species per plot; t-test, alpha <0.1).

CONCLUSIONS

Three distinct vegetative communities were described for both longleaf plantation and natural sites across a soil moisture gradient at the Savannah River Site. Presence/absence of the B horizon, soil pH, and percent sand in the underlying soil horizons (B or C) were the most discriminating environmental variables separating plant communities on longleaf plantation sites. On natural stands, eleven discriminating variables were used to separate plant communities: the presence/absence of the B horizon, landform index, levels of soil magnesium, sodium, calcium, nitrogen, potassium, and organic matter, and percent sand in respective horizon (A, B, and C horizons). Variables controlling the distribution of vegetation among natural groups are not as clearly defined as plantation groups. The presence or absence of a B horizon was the most discriminating environmental variable discriminating among groups for both plantation and natural stands.

Plots were separated into two distinct associations based on origin (plantation or natural). Further, the most similar groups of plots between plantation and natural stands were those that occurred on the most extreme xeric end of the soil moisture gradient. Although overall species richness was significantly higher on natural stands, vegetation composition and structure on these sites were most similar for both xeric plantations and natural stands. This work suggests that well-burned xeric longleaf plantations that have

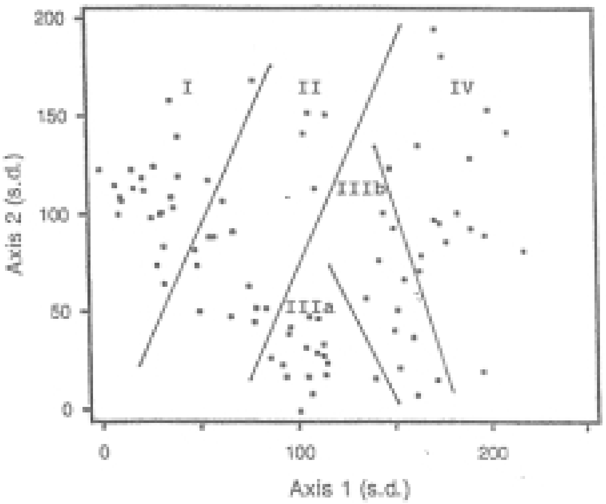


Figure 5—Final ordination of both plantation and natural plots (n = 84) using species presence/absence values.

undergone limited soil disturbance may not be as degraded as previously thought (Noss 1989; Abrahamson and Hartnett 1990).

Out of the 265 species found on plantation sites sampled, about 90 percent were judged to be species representative of natural or native longleaf pine sites. The lack of compositional differences between xeric plantation and natural stands suggests that restoration of the herbaceous layer of longleaf plantations may not be as complex as often thought. Restoration of plantation sites may require the reintroduction of only several native species to the landscape, as well as management practices best suited to maintain natural conditions, such as frequent burning and thinning of the canopy to restore herb vigor.

ACKNOWLEDGMENTS

Financial support was provided by the U.S. Department of Energy-Savannah River Site, U.S. Department of Agriculture Forest Service, Savannah River Natural Resource Management and Research Institute, and Southern Research Station.

REFERENCES

Abrahamson, W.G.; D.C. Hartnett. 1990. Pine flatwoods and dry prairies. In: Myers, R.L. & J.J. Ewel (eds), Ecosystems of Florida, University of Florida Press, Orlando, FL: 103-149.

Afifi, A.A.; and V. Clark. 1990. Computer-Aided Multivariate Analysis. 2nd Ed. New York: Van Nostrand Reinhold. 505 p.

Allaby, M. 1994. The Concise Oxford Dictionary of Ecology. Oxford University Press: 415.

Christensen, N.L. 1988. Vegetation of the southeastern coastal plain. North American Terrestrial Vegetation. M.G. Barbour and W.D. Billings, eds. Cambridge University Press, Cambridge: 317-363.

Cooke, C.W. 1936. Geology of the Coastal Plain of South Carolina. Geologic Survey Bulletin No. 867, U.S. Department of Interior. 196 p.

Frost, C.C. 1993. Four Centuries of Changing Landscape Patterns in the Longleaf Pine Ecosystem. In: Proceedings from the Tall Timbers Fire Ecology Condference, No. 18, The Longleaf Pine Ecosystem: ecology, restoration and management, Tall Timbers Research Station, Tallahassee, FL. 17-37.

Frost, C.C. 1997. Presettlement Vegetation and Natural Fire Regimes of the Savannah River Site. New Ellenton, SC: A Report prepared for the Savannah River Forest Station, U.S. Forest Service, 179 p.

Harcombe, P.A.; J.S. Glitzenstein; R.G. Knox; S.L. Orzell; E.L. Bridges. 1993. Vegetation of the longleaf pine region of the west Gulf Coastal Plain. In: Proceedings of the Tall Timbers Fire Ecology Conference, No. 18, The Longleaf Pine Ecosystem: ecology, restoration and management, Tall Timbers Research Station, Tallahassee, FL. 83-104.

Hill, M.O. 1979b. TWINSPAN: A FORTRAN program for averaging multivariate data in an ordered two-way table by classification of the individuals and attributes. Department of Ecology and Systematics, Cornell University, Ithaca, NY. 52 p.

Hutto. C. J.; V. B. Shelburne; S. M. Jones. 1999. Preliminary ecological land classification of the Chauga Ridges Region of South Carolina. Forest Ecology and Management. 114: 383-393.

Jones, S.M.; D.H. Van Lear; S.K. Cox. 1981. Major Forest Community Types of the Savannah River Plant: A Field Guide. Department of Forest Resources, Clemson, SC. 103p. (79p. + 24 illustrations = 103 pp.)

Jones, S.M.; D.H. Van Lear; S.K. Cox. 1984. A vegetation-landform classification of forest sites within the upper Coastal Plain of South Carolina. Bulletin of the Torrey Botanical Club. 111(3): 349-360.

Landers, J.L.; D.H. Van Lear; W.D. Boyer. 1995. The Longleaf Pine Forests of the Southeast: Requiem or Renaissance? Journal of Forestry. 39-44.

McCune, B.; M. J. Mefford. 1999. PC-ORD. Multivariate Analysis of Ecological Data, Version 4. MJM Software Design, Gleneden Beach, Oregon, USA.

Mitchell, R.K.; L.K. Kirkman; S.D. Pecot; C.A. Wilson; B.J. Palik; L.R. Boring. Regulation of Ecosystem Function Across Complex Environmental Gradients in Longleaf Pine (*Pinus palustris*)-Wiregrass (*Aristida Stricta*) Woodlands. Joseph W. Jones Ecological Research Center at Ichauway.

Mueller-Dombois, D.; Ellenberg, H. 1974. Aims and methods of vegetation science. New York, NY: Wiley.

Myers, R.K.; R. Zahner; S.M. Jones. 1986. Forest Habitat Regions of South Carolina. Clemson University, Department of Forest Resources, series No. 42: 31 + map.

Noss, R.F. 1989. Longleaf pine and wiregrass: keystone components of an endangered ecosystem. Natural Areas Journal 9: 211-213.

Peet, R.K.; D.J. Allard. 1993. Longleaf Pine Vegetation of the Southern Atlantic and Eastern Gulf Coast Regions: A Preliminary Classification. In: Proceedings of the Tall Timbers Fire Ecology Conference, No. 18, The Longleaf Pine Ecosystem: ecology, restoration and management, Tall Timbers Research Station, Tallahassee, FL: 45-81.

Peet, R.K.; T.R. Wentworth; P.S. White. 1998. A Flexible, multipurpose Method for Recording Vegetation Composition and Structure. Castanea. 63: 262-274.

Timbers Research Station, Tallahassee, FL. 83-104.Hill, M.O. 1979a. DECORANA: A FORTRAN program for detrending correspondence and reciprocal averaging. Department of Ecology and Systematics, Cornell University, Ithaca, NY. 52 p.

SAS Institute. 1990. SAS Users's Guide: Statistics. Version 6 ed. SAS Institute, Cary, NC. 584 p.

Van Lear, D.H.; S.M. Jones. 1987. An Example of Site Classification in the Southeastern Coastal Plain Based on Vegetation and Land Type. Southern Journal of Forestry. 11:23-27.

Walker, J.L.; W.D. Boyer. 1993. An Ecological Model and Information Needs Assessment for Longleaf Pine Ecosystem Restoration. Silviculture: From the Cradle of Forestry to Ecosystem Management, Proceedings of the National Silvicultural workshop, Hendersonville, NC. 138-144.

UNDERSTORY RESTORATION IN LONGLEAF PINE PLANTATIONS: OVERSTORY EFFECTS OF COMPETITION AND NEEDLEFALL

Christa M. Dagley, Timothy B. Harrington, and M. Boyd Edwards[1]

Abstract—Overstory and midstory vegetation layers strongly limit abundance and species richness of understory herbaceous plants in longleaf pine (Pinus palustris Mill.) plantations. However, the separate effects of overstory competition and needlefall remain unknown and are the subject of this study. Four levels of overstory thinning were applied to 0.10-hectare plots in each of three 13- to 15-year-old plantations at the Savannah River Site, resulting in 0, 25, 50 and 100 percent pine stockings. Four split plots were established within each main plot: trenching (presence or absence) to eliminate pine root competition and needlefall (presence or absence). Containerized seedlings of selected herbs were grown in a greenhouse, planted within each treatment, and their abundance and size were monitored during 1999-2000. Soil surface temperature and availabilities of light, soil water, and soil and foliar nutrients also were measured periodically. Light availability and temperature each decreased with pine stocking, while in specific months, availabilities of soil water and nitrogen were greater in the presence versus absence of trenching. Reductions of seedling performance with increasing pine stocking were less in the presence versus absence of trenching. Certain species demonstrated shade tolerance, while others had optimal growth at 0 percent pine stocking. For several species, cover increased (1999) and then decreased (2000) in response to accumulation of needlefall. Results indicate that plant responses to light availability were strongly regulated by soil water availability and needlefall.

INTRODUCTION

Longleaf pine once dominated one of the most extensive forest ecosystems in North America, but today only 3 percent of its original distribution remains (Landers and others 1995). The primary factors thought to be responsible for the near disappearance of these forests are regenerative failure of longleaf pine, fondness of feral livestock for the seedlings, and fire suppression during the 20th century (Frost 1993).

Natural longleaf pine forests are distinguished by their diverse herb dominated understory communities and associated animal communities (Glitzenstein and others 1993). Fire suppression since 1920 has resulted in the replacement of longleaf pine savannahs with dense, stratified stands of overstory pines, midstory hardwoods, and understory shrubs. In many cases, loblolly pine (*Pinus taeda* L.) has become dominate because its shade tolerance and seed production are superior to those of longleaf pine (Baker and Langdon 1990). In these replacement stands, midstory hardwoods often consist of the turkey oak (*Quercus laevis* Walt.), bluejack oak (*Quercus incana* Bartr.), and blackjack oak (*Quercus marilandica* Muenchh.). Understory vegetation can be large and abundant with species such as sumac (*Rhus spp*.), sparkleberry (*Vaccinium spp*.), and waxmyrtle (*Myrica cerifera* L.). In addition, vine species such as Japanese honeysuckle (*Lonicera japonica* Thunb.), yellow jessamine (*Gelsemium sempervirens* St.Hil.), and greenbriers (*Smilax spp.*) invade the site. These conditions reduce light availability in the understory, and thereby limit diversity of associated plant and animal species (Harrington and Edwards 1999, Johannsen 1998).

To restore longleaf pine communities it is often necessary to plant longleaf pine and to reintroduce understory herbs. However, in order for community restoration to be successful, key factors that limit establishment and maintenance of reintroduced understory herbs must be identified. In fall 1998, research was initiated at the Savannah River Site in plantations of longleaf pine to separate and quantify overstory effects for light, water, and needlefall on a variety of native perennial herbaceous species. Results of this research will be used to aid efforts to restore native longleaf pine communities and to improve our understanding of overstory and understory interactions.

METHODS

The study was initiated within three 13- to 15-year-old longleaf pine plantations at the Savannah River Site, a National Environmental Research Park near Aiken, SC. Soils for the three sites (blocks) consist of Lakeland, Troup, and Blanton sands. In October 1998, basal area of overstory pines was thinned to four stocking levels (0, 25, 50, and 100 percent of the average basal area of unthinned stands) in single 0.1-hectare plots at each site. To remove potential confounding influences from non-pine species, this vegetation was eliminated from the plots by periodic applications of non-soil active herbicides, glyphosate and triclopyr. Within

[1]Graduate Student and Associate Professor, School of Forest Resources, University of Georgia, Athens GA; Research Ecologist, Southern Research Station, USDA Forest Service, Athens GA, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

each stocking level, four 1.2-meter x 13.7-meter split plots were installed to provide a 2 x 2 factorial arrangement of the presence or absence of trenching or needlefall. In the trenched treatments, a Ditch Witch® was used to excavate linear trenches around each split plot to a depth of approximately 0.5 meters. To prevent future encroachment of pine roots each trench was lined with aluminum flashing and then refilled. In the needlefall treatment, controlled levels of needlefall (presence or absence) were applied monthly at a rate equal to twice that of a fully-stocked stand, where monthly needlefall rates were based on existing data from Harrington and Edwards (1999). Each split plot was divided into eleven quadrats of area one square meter within which a single species was planted. One quadrat remained unplanted throughout the duration of the study and was used to measure soil water content. Each quadrat was kept free of all competing vegetation with monthly hand weeding.

A group of native, perennial, herbaceous species that varied in size and growth form was selected for this study (table 1). Seeds of each species were collected at or near the study sites, germinated via cold stratification and their seedlings were grown for four months within containers. In May 1999 and 2000, populations of 36 seedlings per species were planted within the quadrats with a container dibble. Containerized seedlings of longleaf pine also were planted. A total of thirteen species were planted in each of the split plots (eight in 1999 and five in 2000). To provide room for the three additional species of the 2000 cohort, three species from the 1999 cohort were removed in April 2000.

In combination, the thinning and trenching treatments enabled experimental separation of interference from the overstory pines into above- and below-ground components. Likewise, the needlefall treatment was applied independent of pine stocking level, and thus its effects can be quantified separately. Measurements of environmental conditions (crown closure via vertical densitometer, soil water content via time domain reflectometry, available soil nitrogen via KCL extractions, and foliar nitrogen, potassium, and phosphorus content) and soil surface temperature were taken periodically during each growing season. Performance of planted species (survival, cover, height, and biomass) also was monitored during each growing season.

RESULTS

Environmental Conditions

The long-term average growing season (May-October) precipitation for Aiken SC is 66 centimeters (weather.com). Precipitation for the 1999 and 2000 growing season was 56 and 48 centimeters, respectively (Savannah River Forest Station 2000). Although both years were drier than normal, precipitation was sufficient in 1999 at the time of planting. In contrast, rainfall for May 2000 was less than 1.3 centimeters, which negatively impacted survival of seedlings planted in that year. Soil surface temperature declined linearly with pine stocking and the difference between 0 and 100 percent stockings averaged 3.2 degrees Centigrade.

In the two growing seasons since thinning of pines, basal area has increased by 15, 28, and 32 percent in the 100, 50, and 25 percent stocking levels, respectively. In contrast, crown closure has increased at a much slower rate, particularly in the 25 and 50 percent stocking levels where little change occurred from 1999 to 2000. The thinning and trenching treatments had no visually detectable influence on pine vigor except for mortality of two trees that died from unknown causes.

In the absence of trenching, soil water declined consistently as pine stocking increased from 50 to 100 percent. However, in the presence of trenching, soil water availability was influenced very little by pine stocking. These responses indicate that the trenching treatment was successful in partitioning competition from pine into above- and below-ground components. During several periods in the 1999 and 2000 growing seasons, soil water in non-trenched split plots dropped below 6 percent, the assumed permanent wilting point for these soils.

In three of the five months of monitoring, available nitrogen differed significantly among treatments. In June, available nitrogen was greater in the presence versus absence trenching. Available nitrogen in August was less in the presence versus absence of needlefall, while the opposite trend occurred in September.

Plant Responses

Survival of the 1999 cohort was high, averaging greater than 80 percent for the eight species. In contrast, survival of the 2000 cohort was low probably because of the severe spring drought, averaging less than 10 percent for the five species. However, first-year survival of each cohort was greater in the presence versus absence of trenching. During the second growing season, survival of the 1999 cohort was greater in the presence of trenching and absence of needlefall.

The species of the 1999 cohort varied in their patterns of response to the pine stocking, trenching, and needlefall treatments; however, the highest performance was observed when pine stocking was 0 percent. In addition, most species had superior performance in the presence versus absence of trenching. Cover, height, and biomass responses of the 2000 cohort plant could not be analyzed because of poor survival.

Anthaenantia villosa, *Pinus palustris*, *Liatris elegans*, and *Sorghastrum secundum* demonstrated an interactive response pattern. They exhibited excellent performance even under 100 percent stocking of longleaf pine, as long as availability of below-ground resources did not severely limit their growth (i.e., in trenched split plots). However, if below-ground resources were in growth-limiting supplies (i.e., in non-trenched split plots), performance declined considerably as pine stocking increased and associated availability of light decreased. These species also exhibited superior performance in the presence versus absence of needlefall, except at full stocking in non-trenched split plots where needlefall negatively affected species' performance.

Solidago odora, *Pityopsis graminifolia*, and *Lespedeza hirta* demonstrated an additive response pattern to the

Table 1—Species planted in the longleaf pine study at the Savannah River Site

Scientific name	Characteristics
Anthaenantia villosa (Michx.) Beauvois[a]	Ascending perennial grass; short rhizomes
Lespedeza hirta (L.) Hornemann[a]	Erect perennial forb; nitrogen fixer
Liatris elegans (Walt.) Michx.[a,c]	Erect perennial forb; corms
Pinus palustris Mill.[a]	Tree
Pityopsis graminfolia (Michx.) Nutt.[a,c]	Erect perennial forb; rhizomes
Solidago odora Aiton[a,c]	Erect perennial forb; short rhizomes
Sorghastrum secundum (Ell.) Nash[a]	Ascending, tufted perennial grass; short rhizomes
Sporobolus junceus (Michx.) Kunth[a]	Erect to sprawling perennial grass
Andropogon ternarius (Michx.)[b]	Erect perennial grass; short rhizomes
Carphephorus bellidifolius (Michx.) T.& G.[b]	Ascending perennial forb
Chrysopsis gossypina (Michx.) Ell.[b]	Erect, decumbent, or ascending perennial forb
Desmodium ciliare (Muhl. Ex Willd.) DC.[b]	Erect perennial forb
Eragrostis spectabilis (Pursh) Steudel[b]	Erect perennial grass; short rhizomes

[a]May 1999 planting;
[b]May 2000 planting;
[c]Removed

treatments. Species' performance increased as pine stocking decreased and in the presence of trenching; however, the two factors did not interact.

Foliar nitrogen of *Sporobolus junceus* was greater in the presence versus absence of needlefall, indicating a "fertilizer" effect. Per-plant amounts of nitrogen, phosphorous, and potassium increased as pine stocking decreased, a direct result of increases in plant biomass.

CONCLUSIONS

This research has increased our understanding of the complexity by which overstory pines affect understory vegetation through resource competition and needlefall. Performance of most species was increased when availability of below-ground resources was elevated, regardless of pine stocking. In addition, effects of trenching and needlefall interacted with pine stocking level for certain species, indicating that limiting effects of shade can be either moderated or exacerbated by variation in below-ground resources or presence of needlefall. The two response patterns, interactive and additive, provide a means of classifying herbaceous species according to their potential performance in longleaf pine community restoration, given specific overstory, understory, and needlefall conditions of longleaf pine plantations.

Research results indicate that containerized reproduction can be a successful method for restoring herbaceous species if rainfall is adequate at the time of planting. Optimal performance of planted species is likely to occur in large canopy openings with minimal root competition from associated woody and herbaceous species.

ACKNOWLEDGMENTS

This research was funded by the U.S. Department of Energy, Savannah River Biodiversity Program through the U.S.D.A. Forest Service under DE-IA09-00SR22188. We thank J. Blake for his logistical support and research ideas, J. Gatch, B. Miley, J. Brown, and J. Campbell for assistance with plant propagation, data collection, and plot maintenance, and R. Daniels for advice regarding statistical analysis.

REFERENCES

Baker, J.B.; O.G. Langdon. 1990. *Pinus taeda* L. P. 497-512 in Silvics of North America: Vol. 1. Conifers, Burns, R.M. and B.H. Honkala (tech. coords.). Agric. Handb. 654. Washington DC: U.S. Department of Agriculture, Forest Service. 675 p.

Frost, C.C. 1993. Four centuries of changing landscape patterns in the longleaf pine ecosystem. P. 17-43 In: Hermann, S.M.,ed., The longleaf pine ecosystem: ecology, restoration, and management, Proceedings of the 18th Tall Timbers Fire Ecology Conference, Tall Timbers Research Station, Tallahassee, FL. 17-43.

Glitzenstein, J.S.; D. Hardin; B. Means; K. Outcalt; J. Walker; N. Wilkins. 1993. Panel Discussion: silviculture effects on groundcover plant communities in longleaf pine forests. In: Hermann, S.M., ed., The longleaf pine ecosystem: ecology, restoration, and management, Proceedings of the 18th Tall Timbers Fire Ecology Conference, Tall Timbers Research Station, Tallahassee, FL: 357-370.

Harrington, T.B.; M.B. Edwards. 1999. Understory vegetation, resource availability, and litterfall responses to pine thinning and woody vegetation control in longleaf pine plantations. Canadian Journal of Forest Research. 29: 1055-1064.

Johannsen, K.L. 1998. Effects of thinning and herbicide application on vertebrate communities in young longleaf pine plantations. Athens, GA: University of Georgia. M.S. thesis. 48 p.

Landers, J.L.; D.H. Van Leer; W.D. Boyer. 1995. The longleaf pine forests of the Southeast: requiem or renaissance? Journal of Forestry. 93(11): 39-44.

Weather.com. 2000. Monthly averages and records, Aiken SC.

ECOLOGICAL RESTORATION THROUGH SILVICULTURE—A SAVANNA MANAGEMENT DEMONSTRATION AREA, SINKIN EXPERIMENTAL FOREST, MISSOURI

Edward F. Loewenstein and Kenneth R. Davidson[1]

Abstract—In 1998, a project was initiated to demonstrate techniques and evaluate the efficacy of reducing overstory tree density and reintroducing fire in order to develop the tree composition, structure, and herbaceous complex typical of a savanna. On three study areas, two dominated by oak and one by shortleaf pine, the total basal area of all trees = 1.6 inches DBH was thinned to approximately 40 feet^2 basal area per acre during the 1998-99 dormant season. Prescribed burns were conducted in April 1999 and April 2000. After assessing mortality from the fire, the residual basal area was adjusted to 35 feet^2 per acre during the 1999 growing season.Pretreatment inventories conducted during August of 1998 tallied over 45 herbaceous and woody understory species. During the first-year post-treatment inventory (August 1999), 20 new herbaceous species were identified on the treatment plots. Following the second prescribed fire, 17 additional herbaceous species were tallied (August 2000). The most abundant of these species were fireweed and pokeweed. Of the woody understory species (<1.6 inches DBH) present on the sampling plots, only the oaks and hickories did not exhibit a substantial change in the number of stems per acre following treatment. Blackhaw was eliminated from the understory following the prescribed burn and the numbers of black cherry, red maple, dogwood, and shortleaf pine decreased by more than 50 percent. Species that benefited from the treatment included black gum (+210 percent), sassafras (+40 percent), sumac (+2110 percent), and post oak (+494 percent). Initial treatments greatly modified the overstory structure and, thus, the understory light regime. This in turn has affected an immediate and marked shift in the understory complex of herbaceous and woody plants.

INTRODUCTION

Management and restoration of savannas has become a topic of considerable interest in recent years. These are among the most diverse systems in the Northern Temperate Zone, but have declined in area by over 99.9 percent during the last 100 years (Nuzzo 1986). Much of this reduction has been due to changes in land use across the Midwest (e.g. agricultural conversion). However, in many areas including the Ozark Highlands, over the last 50-100 years fire suppression has caused a marked reduction in small diameter tree mortality. This in turn has affected a change from savanna to closed canopy forest with a corresponding reduction in herbaceous species diversity as understory light levels diminished (Jenkins 1997).

If fire was the primary disturbance factor that maintained savanna ecosystems on the landscape and suppression of this disturbance caused a change in the basic makeup of the system, then one might expect that the reintroduction of fire should restore the ecosystem to its original structure and function. Unfortunately, this has not proven to be the case, at least not within a reasonably short time frame. In an attempt to restore pre-settlement structure and composition in a Missouri oak forest, Blake and Schuette (2000) reported that reintroduction of regular prescribed fires had no effect on overstory species composition or structure after 10 years. Similar results were reported after 15 years in Minnesota (White 1986) and after 20 years in Illinois (Taft and others 1995). Although reintroduction of a fire regime greatly reduced the shrub layer and the number of small diameter trees (Blake and Schuette 2000, White 1986) the effect on large diameter canopy dominant trees was slight. These trees tend not to be affected by low intensity prescribed fire. In order to recreate pre-settlement conditions using fire alone, either higher intensity burns would need to be used (with the associated risk of a stand replacing fire or escape of the burn onto adjacent property) or sufficient time would need to pass for natural mortality to occur within the dominant canopy of the stand. An alternative is to cut or kill a sufficient number of large diameter stems to recreate the desired stand structure immediately.

Restoration ecology may be defined as active management that seeks to return a 'degraded' system to the structure, composition, and disturbance regime of some reference time or ecosystem (after Wagner and others 2000). This 'reference state' is often defined as that which existed pre-European settlement. Thus, restoration ecology actively manipulates a system to achieve a desired vegetative

[1]Research Forester, USDA Forest Service, North Central Research Station, 202 Natural Resources Building, Columbia, MO 65211-7260 eloewenstein@fs.fed.us; Forestry Technician, USDA Forest Service, North Central Research Station, Hwy 19 South, Salem, MO 65560, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Pre-treatment overstory measurements

	Basal area (ft^2/acre)	Stocking (percent)	Canopy cover (percent)	Light transmission (percent)
Savanna 1	112.5 ± 11.8	100.2 ± 7.8	80	14.4 ± 12.3
Savanna 2	79.4 ± 7.1	69.6 ± 5.5	71	25.8 ± 28.3
Savanna 3	152.5 ± 22.5	120.2 ± 13.4	99	4.4 ± 3.9

state. In the same vein, silviculture is defined as the art and science of controlling the establishment, growth, composition, health, and quality of forests and woodlands to meet the diverse needs and values of landowners and society on a sustainable basis (Helms 1998). In other words, active manipulation of forest stands to meet landowner objectives. Wagner and others (2000) suggest that restoration differs from silviculture in that it substitutes a reference condition for specific objectives. This seems to be a difference without real substance. If a landowner lists as an objective the creation of some reference condition, the silviculturist can develop a prescription to achieve that end, subject to the same constraints as any other objective (i.e. is the objective biologically possible, is it mutually exclusive of another stated objective, are there sufficient resources to achieve the stated objective, etc…). Such prescriptions have been written and implemented for restoration of pre-settlement ponderosa pine habitat (Lynch and others 2000) and for creating/restoring optimal goshawk habitat (Long and Smith 2000). As an added bonus, the silvicultural methods used to arrive at the desired vegetative state may generate income to the landowner.

The Sinkin Experimental Forest is used primarily for research and demonstration. This demonstration site was not intended nor was it designed to be a formal experiment or comparison. There is no true statistical replication and the prescribed burns were not implemented or monitored in sufficient detail to draw conclusions about cause and effect. We initiated this project to demonstrate techniques and evaluate the efficacy of reducing stand density and reintroducing fire in order to develop the tree composition and structure and herbaceous complex typical of a savanna/oak-woodland. It was also designed to show small landowners another option for land management where timber production may not be the driving force on a parcel, especially in an area where oak decline is or might be a problem.

Table 2—Post-treatment overstory measurements

		Basal area (ft^2/acre)	Stocking (percent)	Light transmission (percent)
Savanna 1	1999	35.5	33.4	73
	2000	32.8	29.1	74
Savanna 2	1999	26.9	27.4	67
	2000	25.6	24.3	79
Savanna 3	1999	35.3	21.2	75
	2000	29.0	17.4	83

METHODS

Site Description

The savanna demonstration area consists of three separate stands on the Sinkin Experimental Forest, which is located in south central Missouri in the Ozark Highlands. Savanna 1 is approximately 2.75 acres in size and is located on an upper slope with a western aspect. The site index is 60-65 feet (for black oak, base age 50 years) and the pretreatment overstory was composed primarily of black oak, white oak, post oak, and hickory (average age 95 years). The midstory and understory tree species were primarily black gum, dogwood, and sassafras. During the 1998 growing season, this stand supported approximately 108 $feet^2$/acre of basal area (all trees = 1.6 inches DBH) (table 1).

Savanna 2 is 4 acres in size and lies on a southwest facing upper slope. The overstory was dominated by 85-year-old scarlet oak, black oak, white oak, and shortleaf pine. Like savanna 1 the site index was in the low 60's. Understory trees were principally hickory, black gum, and dogwood. This stand had been affected by oak decline, there were several large dead or dying scarlet and black oaks; this reduced standing density to approximately 80 $feet^2$/acre basal area. Because of the relatively low density of this stand, there was a well-developed understory and midstory of oak advance reproduction and woody shrubs.

Savanna 3 covers 3 acres on an upper west-facing slope. It was the only shortleaf pine dominated site. The trees were approximately 80 years old and the site index was estimated at 65 feet. Smaller pole sized trees in this stand included white oak, post oak, black oak, scarlet oak, hickory, black gum, and dogwood. There were few subcanopy or understory trees in this stand, probably due to the high density (153 $feet^2$/acre basal area).

Measurements

In each of the three stands, a pre-treatment inventory of the overstory and understory was made during the 1998 growing season. Three circular one-third acre overstory plots were established on each site and all trees = 1.6 inches DBH were tallied by species and DBH. Post-treatment inventories were conducted during the 1999 and 2000 growing seasons.

Data on all understory woody stems (< 1.6 inches DBH) was collected on 96 one-five hundredth acre circular subplots (24, 36, and 36 plots on savannas 1, 2, and 3, respectively). This vegetation was tallied by species, origin, height class, and number of stems. Herbaceous and semi-woody stems were sampled in a one square-meter frame located at an azimuth of 90 degrees and 2 meters distance from subplot center. All vegetation was tallied by species, height class, and percent cover.

Canopy closure was measured at each subplot center with a densitometer. In addition, canopy photographs were taken using an 18mm lens and PAR (photosynthetically active radiation) was sampled with a sunfleck ceptometer.

Prescription

Our target overstory structure was to have approximately 35 feet^2/acre of large, well-spaced trees. This density would equate to approximately 50 percent canopy closure if the trees had been open grown (Law and others 1994). However, since the initial stands were fairly high density, closed canopy stands, the crowns of the residual stems were less developed than open grown trees and the resulting canopy closure would be reduced. As the residual overstory trees expand their crowns, adjustments to stand density will be made in future years to ensure that canopy closure remains within the 10 to 50 percent range cited as typical for Missouri Ozark savanna systems (Nuzzo 1986).

Table 4—Pre-treatment herbaceous plants inventoried

Species	Species
Virginia creeper	
Desmodium	New jersey tea
Wild grape	False solomans seal
Blackberry	American feverfew
Vaccinium	Horseweed
Carolina rose	Horse mint
Helianthus	False buck wheat
Poison ivy	Panicum spp.
Oxalis	Panicum ravenellii
Carex spp.	Panicum commutatum
Carex complinata	Panicum lanuginosum
Bracken fern	Dittany
Cinquefoil	Pussy's toes
Solidago	Lespedeza
Aster spp.	Broom sedge
Aster turbinellus	Bedstraw
Poverty grass	Corral berry
Wood angelica	Goats rue
Hog peanut	Green briar
Milkweed	Rue anemone
Violet	Flowering spurge
False flax	Meadow parsnip
Virginia snake root	Christmas fern

Following the pretreatment inventory, the three study sites were marked to leave approximately 40 feet^2/acre of basal area in all stems = 1.6 inches DBH. Leaving 40 feet^2/acre allowed for compensation based on mortality caused by logging damage or the prescribed fire. Leave trees were selected based on canopy dominance, species, vigor, and spacing.

Table 3—Understory woody stem density (< 1.6 inches DBH) averaged across all three sites

	Pre-treatment (stems per acre)	Post-treatment burn 1 (stems per acre)	Post-treatment burn 2 (stems per acre)
White oak	711	763	323
Black oak	1593	1033	942
Scarlet oak	407	513	478
Post oak	142	228	844
Hickories	527	561	927
Black cherry	176	92	43
Black gum	619	1169	1918
Red maple	335	132	100
Dogwood	713	314	340
Sassafras	1065	2956	1487
Sumac	38	478	840
Savanna 2 only			
Wild plum	14	24	0
Shortleaf pine	359	85	143

Table 5—Newly occurring herbaceous species following treatment

Species	Species
Fireweed	Black haw
Pokeweed	Fake dandelion
Nightshade	Juncos tenius
Goats rue	Ambrosia
Wild strawberry	Big blue stem
Little blue stem	Partridge pea
Hawk weed	Queen Anne's lace
Kentucky blue grass	Fimbristylis
Skull cap	Dogbane
Wild indigo	Wild geranium
Violet	Prickly lettuce
Wild oat grass	Angle pod
False buckwheat	Trailing milk pea
Aromatic sumac	Horse nettle
Pink wild bean	

The largest trees of the most fire resistant species were preferentially left in the stand. During the 1998-99 dormant season, the three stands were thinned. A horse logger was contracted to conduct the harvest for two reasons. First, the total area treated and the volume removed were relatively small. The logger was willing to bid on this sale and was able to complete the project on our timetable. More importantly, the site impact from horse logging is minimal. The horses are able to maneuver in a partially cut stand better than most skidders (residual stand damage was almost non-existent) and upon completion of the harvest operation, the main skid trail looked more like a backcountry hiking trail than a skid trail.

A prescribed burn was conducted on April 7, 1999. Mortality was assessed and the residual basal area was adjusted to 35^{2}feet/acre in May 1999. A second prescribed burn was conducted in April of 2000. There was difficulty in getting the fire to carry across the stands during the second year burn because of low fuel loads and discontinuous fuels. For this reason, future burns will be conducted every other year following an assessment of the fuel conditions on each site.

RESULTS AND DISCUSSION

Overstory

As was mentioned, our target overstory density was 35 feet^2/acre of basal area. Following initial treatments, savannas 1 and 3 were extremely close to the mark at 35.5 and 35.3 feet^2/acre, respectively (table 2). Savanna 2 is somewhat under stocked because of the large incidence of oak decline on this site in the black and scarlet oak components. This stand had somewhat higher fire related mortality, probably due to the higher fuel loads that were caused by the relatively low initial density and subsequently higher light transmission into the understory, which caused a buildup in understory vegetation.

Notice that the stocking percentage is very different between savannas 1 and 3 even though the residual basal area is nearly the same (table 2). Many smaller diameter stems were left on savanna 1 to meet residual stocking demands, which were able to be met with fewer large diameter stems on savanna 3. This difference in overstory structure will also affect percent canopy closure and light transmittance through the canopy. Unless fire related mortality preferentially affects the smaller diameter trees on savanna 1 in the future, additional thinning may be required in this stand first to maintain the desired open structure.

Some additional mortality did occur between years 1 and 2, but this was likely the result of our current drought exacerbating the oak decline problem rather than a direct result from the prescribed fires. At the end of 2000, the Sinkin Experimental Forest had a cumulative 2-year precipitation deficit of nearly 24 inches from a 50-year average annual precipitation rate of 44 inches (data on file at the Columbia Forest Science Lab, Columbia, MO).

Understory

The prescribed fires caused some marked and immediate changes in the understory (< 1.6 inches DBH) woody components of these stands (table 3). Except for the marginal effect of the removal of the overstory trees on these stems (nothing < 1.6 inches DBH was cut during the thinning operation) the change in density was caused primarily by the prescribed fire. Species that experienced large reductions in numbers include: black cherry (-75 percent), dogwood (-52 percent), red maple (-70 percent), shortleaf pine (- 60 percent), and blackhaw was eliminated from the understory. Similarly, some species greatly benefited from the introduction of fire: black gum (+210 percent), sassafras (+40 percent), sumac (+2110 percent), and post oak (494 percent).

Without regard to the direction of change in woody understory numbers, the general dynamic seems to be similar to that reported by Blake and Schuette (2000). The largest of the understory stems have been eliminated. Although many of these stems are resprouting from the root collar (unreported data), it seems that the recruitment of reproduction into the overstory will be reduced or eliminated with regular prescribed fire. Thus, if the disturbance regime (regular fire) is continued, it should be sufficient to maintain the desired overstory structure. However, it should be noted that episodic fire free intervals will be needed at some time in the future so sufficient reproduction can be recruited into the overstory to replace trees lost to mortality.

Herbaceous Vegetation

Pretreatment inventories tallied over 45 herbaceous and semi-woody understory species (table 4). Following the initial treatment (cut and burn), an additional 20 species were identified on the sites. After the second prescribed burn, another 17 species were found (table 5). Following the first year's treatment, 8 species were eliminated from the study sites: Virginia snake root, poverty grass, corral berry, Christmas fern, bedstraw, meadow parsnip, green briar, and rue anemone. However, during the second inventory following treatment, last 4 of these species once again showed up on our tally.

Fireweed and pokeweed arrived in profusion across all of the study sites following the first year's treatment and increased markedly in prominence following the second prescribed fire. By August 2000, fireweed occurred on 82 percent of our subplots with an average cover of 10 percent. Pokeweed appeared on 21 percent of the plots and averaged 14 percent cover. Six other species were fairly common: nightshade (6 percent of plots, 3 percent cover), little blue stem (13, 5), goat's rue (3,9), hawk weed (8, 3), wild strawberry (6, 3), and hog peanut (5, 3). The speed these sites were colonized was somewhat surprising given the fact that they have been under a closed canopy forest for over 40 years and continuous forest cover currently surrounds them for several miles. Either the seed source for these plants is amazingly persistent in the soil, or they have mechanisms for traveling great distance.

CONCLUSIONS

Silviculture need not have timber production as an exclusive (or even primary) objective. The goal is to produce a forest vegetative state that meets the objectives of the landowner. In the case of restoration, that objective is some historical or reference state. Our objective on this demonstration area was to develop the tree composition, structure, and herbaceous complex typical of a savanna. To achieve this goal, a prescription was designed to re-create the overstory structure typical of a pre-settlement Missouri savanna (Nuzzo 1986) and reintroduce the disturbance regime (periodic fire) that historically maintained the reference ecosystem. Initial treatments greatly modified the forest overstory structure, and reduced the litter layer, midstory and shrub layers, greatly increasing light levels at the forest floor. In turn, this has affected an immediate and marked shift in the understory complex of herbaceous and woody plants, nearly doubling the species diversity within two years of initial treatment.

REFERENCES

Blake, J.G.; Schuette, B. 2000. Restoration of an oak forest in east-central Missouri early effects of prescribed burning on woody vegetation. Forest Ecology and Management 139: 109-126.

Helms, J.A. (ed.). 1998. The dictionary of forestry. Bethesda, MD: Society of American Foresters. 210 p.

Jenkins, S.E. 1997. Spatial demography of trees in an oak savanna and adjacent dry chert woodland in the Missouri Ozarks. Columbia, MO: University of Missouri. 116 p. Ph.D. dissertation.

Law J.R., Johnson P.S., and Houf G. 1994. A crown cover chart for oak savannas. Tech. Brief TB-NC-2. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 4 p.

Long, J.N.; Smith, F.W. 2000. Restructuring the forest goshawks and the restoration of southwestern ponderosa pine. Journal of Forestry. 98(8): 25-30.

Lynch, D.L.; Romme, W.H.; Floyd, M.L. 2000. Forest restoration in southwestern ponderosa pine. Journal of Forestry. 98(8): 17-24.

Nuzzo, V.A. 1986. Extent and status of Midwest oak savanna: presettlement and 1985. Natural Areas Journal. 6(2): 6-36.

Taft, J.B.; Schwartz, M.W.; Philippe, L.R. 1995 Vegetation ecology of flatwoods on the Illinoian till plain. Journal of Vegetation Science. 6: 647-666.

Wagner, M.R.; Block, W.M.; Geils, B.W.; Wenger, K.F. 2000. Restoration ecology a new forest management paradigm, or another merit badge for foresters? Journal of Forestry 98(10): 22-27.

White, A.S. 1986. Prescribed burning for oak savanna restoration in central Minnesota. Res. Pap. NC-266. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 12 p.

Site Preparation

Moderator:

JOHN TOLBERT
Mead Corporation

RESPONSE OF SECOND-ROTATION SOUTHERN PINES TO FERTILIZER AND PLANTING ON OLD BEDS—FIFTEENTH-YEAR RESULTS

James D. Haywood and Allan E. Tiarks[1]

Abstract—Two replicated site preparation studies were used to examine the effects of management on loblolly pine (Pinus taeda L.) and slash pine (P. elliottii Engelm. var. elliottii) growth-and-yield in a second rotation on silt loam soils. Treatments included no tillage, flat disking, bedding, and fertilization. After 15 growing seasons of the second rotation in study 1, loblolly pine and slash pine basal area and volume per acre were greater on burned-only plots than on plots mechanically site prepared 38 years earlier. In the first rotation, 15-year-old loblolly and slash pines had averaged 52 and 49 ft tall, respectively; in the second rotation the trees were only 40 and 46 ft tall. In study 2, slash pine responded to 88 lb per acre of phosphorus applied at the beginning of both rotations, but planting on 16-year-old beds had no influence on slash pine growth 15 years later. Cross-rotation comparisons could not be made in study 2 because of age differences when measurements were taken between rotations.

INTRODUCTION

On poorly drained soils in the Southeastern Coastal Plain, pine seedlings have often been planted on beds to improve survival by increasing the volume of unsaturated soil available to roots during rainy periods (Pritchett and Gooding 1975). On west Gulf Coastal Plain silt loam sites where some soils are poorly drained, bedding can be a successful ameliorative treatment if soil depth to the winter water table averages < 1.5 ft (Haywood and others 1990). While the evidence supports bedding on only the most poorly drained sites, bedding is now being used on upland sites in the west gulf region.

Beds are a lasting topographic feature that can disrupt the natural drainage pattern on gently rolling west Gulf Coastal Plain silt loam soils (Haywood 1995). Surface water can pond and adversely affect tree development. Bedding may benefit tree growth through the first five growing seasons only to lose effectiveness by mid- or late-rotation (Derr and Mann 1977; Haywood 1983, 1995). Thus at the end of the rotation, what to do with the beds can be an issue. Should one plant on the old beds, level the site by knocking down the beds, or rework the beds before the next stand of trees is planted?

We studied two sites in central Louisiana to address the issue of whether or not to plant on old beds. At study 1, a second rotation of loblolly pine (*Pinus taeda* L.) and slash pine (*P. elliottii* Engelm. var. *elliottii*) trees was planted on beds created 22 years earlier (Haywood 1994). On study 2, a second rotation of slash pine trees was planted on beds created 16 years earlier (Tiarks and Haywood 1996). This paper reports on how planting on these old beds influenced growth-and-yield after 15 years of the second rotation. At study 1, we also were able to make 15-year height comparisons between the first and second rotations, but because of age differences when measurements were taken, cross-rotation comparisons could not be made for study 2. Earlier growth comparisons between rotations on one or both sites were made by Haywood (1994), Haywood and Tiarks (1995), and Tiarks and Haywood (1996). Soils and nutritional results for both studies were reported by Tiarks and Haywood (1996).

METHODS

Study Sites

The two study areas are located in Rapides Parish, LA, within 1 mi of each other. Study 1 is on Beauregard (fine-silty, siliceous, thermic Plinthaquic Paleudult) and Caddo (fine-silty, siliceous, thermic Typic Glossaqualf) silt loam soils; study 2 is on predominately Beauregard soil. These soils are acidic, have low natural fertility, can be highly productive with good management, and are common in flatwoods of the west Gulf Coastal Plain (Tiarks and Haywood 1996). The Caddo soil occurs on the lower parts of the level-to-slightly sloping landscape, is poorly drained, and may have a perched water table at or just below the surface during extended periods from December through February (Haywood and others 1990). The Beauregard occurs on slightly higher parts of the landscape, is moderately well drained, and has a winter water table between 1.5 and 2.3 ft. The two soils are very similar in surface horizon characteristics and response to site treatments, including fire and tillage.

On both sites, longleaf pine *(P. palustris* Mill.) and hardwoods were clearcut harvested in the 1920s. After harvesting, a cover of mostly grasses and scattered woody plants was maintained in open range by livestock grazing and periodic burning. Before plot establishment and tree planting, the areas were again cut to reduce woody vegetation.

[1]Research Forester and Soil Scientist, Southern Research Station, Alexandria Forestry Center, 2500 Shreveport Highway, Pineville, LA 71360-5500, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Study Establishment

Both studies were established in the 1960s to evaluate disking and bedding as mechanical site preparation methods. Study 1 was established to compare two pine species (loblolly and slash) and three site preparation treatments in a randomized complete block design with four blocks as replicates. Each of the 24 plots (2 pine species times 3 treatments times 4 blocks) measured 144 by 108 ft (0.36 ac). Row spacing was 8 ft, and seedlings were planted 6 ft apart within rows. Measurements were made on the central 10 rows of 10 trees per plot.

Study 2 was established as a randomized complete block split-plot design. There were three main effect site preparation treatments and four blocks as replicates. Only slash pine was planted at study 2. Each of the 12 main plots (3 treatments times 4 blocks) was split into 4 subplots that were 70 by 72 ft (0.12 ac), and to which fertilizer treatments were applied. Row spacing was 10 ft and seedling spacing 6 ft. Tree measurements were made on the center three rows of eight trees per subplot. In both studies, blocking was based on surface drainage.

In study 1, site preparation treatments were: (1) burn-only, all plots were burned in 1960; (2) burn-disk, following burning, some plots were treated with an offset disk harrow once in the fall of 1960 and again in July 1961 to control established grasses; and (3) burn-disk-bed, following burning and disking, technicians created beds averaging 20 in. tall from furrow to crest—before settling—in September 1961 by making two passes with a bedding harrow. The beds were 10 in. tall after 17 years and 8 in. tall after 33 years. The bare-root, 1-0 loblolly and slash pine seedlings were obtained from a Louisiana State nursery. The seedlings were graded and hand planted on the appropriate plots in February 1962. The plots were thinned during the 13th growing season (Haywood 1983) and control burned at least once in the first rotation.

In study 2, the three site preparation treatments were: (1) burned only, (2) disked only, and (3) bedded only. The plots were established in the fall of 1967. The fertilizer treatments applied to one of four subplots in each main plot were: (1) no nutrient amendment, (2) 88 lb per acre of phosphorus (P) as triple superphosphate, (3) 1,000 lb per acre of lime, and (4) a combination of P and lime. The amendments were applied after the burning but before mechanical site preparation so the P and lime were mixed into the soil only on the disked or bedded plots. However, incorporation of P fertilizer is unnecessary on these soils (Shoulders and Tiarks 1980). In February 1969, slash pine seedlings similar in quality to those used in study 1 were hand planted in study 2.

Tiarks and Haywood (1996) outlined all of the treatment applications and dates soil and plant samplings were done for both studies and rotations. In 1983, both studies were clearcut harvested. Logging equipment was not allowed on the plots. After harvest, both study sites were broadcast burned to reduce logging residue and facilitate planting the next year. The disked or bedded plots were not retreated mechanically, so the influence of only the initial site preparation treatments could be evaluated during the second rotation.

In February 1984, the plots on both sites were hand planted with the same species of pine as were planted in the first rotation. Seedlings were obtained from a Louisiana State nursery and were similar in quality and probably better genetically to those used in the first rotation. The seedlings were planted at the original spacing between stumps in the original planting rows.

During the first rotation, grasses were initially the principal competitors with the pine trees, although woody competitors were present at both study sites. During the second rotation, all plots in study 1 were rotary mowed yearly between the rows of pine trees to control the size of woody competitors. Woody vegetation within planted rows was cut down during the eighth growing season. The plots were control burned 10 years after planting.

In study 2, the competition was allowed to change in response to the treatments so no competition control was applied to any of the plots. Where no P had been applied, the competition was mostly grasses in both rotations, but on plots that had received P, the amount of woody competition gradually increased during the first rotation and was much greater in the second.

The lime applied to the first rotation of study 2 had no effect on pine growth (Tiarks 1983), so that treatment was replaced with a nitrogen (N) application of 50 lb per acre applied as ammonium nitrate in the beginning of the eighth growing season of the second rotation. The rate of N was based on pine response to N on nearby Beauregard soils (Shoulders and Tiarks 1983).

Measurements

After 15 growing seasons, total heights were measured with a clinometer, and a diameter tape was used to measure diameter at breast height (d.b.h.). Outside bark total stem volumes were calculated for loblolly (Baldwin and Feduccia 1987) and slash (Lohrey 1985) pines.

Management Effects on Growth Comparisons

At study 1, a thinning of the 13-year-old stands in the first rotation did not affect the total height curve for either species. Therefore, height comparisons could be made between the first and second rotation stands at age 15 years. However, thinning nullified comparing diameter, basal area, or volume differences between rotations after age 10 (Haywood and Tiarks 1995). Nevertheless, pine variables could be compared among treatments at the end of the second rotation.

At study 2, pine beetle (*Dendroctonus* spp. and *Ips* spp.) infestations during the second rotation nullified the usefulness of the diameter, basal area, and volume estimates after age 10 years. Height comparisons between rotations were also not possible past age 10 because of differences in ages when measurements were taken between rotations (Tiarks 1983). However, tree heights could be compared among treatments at the end of the second rotation.

Table 1—For study 1, mean total height, d.b.h., and outside-bark volume and stand density, basal area, and yield for 15-year-old loblolly and slash pines after the second rotation

Pine species and site preparation treatments[a]	Total height	D.b.h.	Volume per tree	Number per acre	Basal area	Total volume
	Feet	*In.*	*Ft^3*	*Count*	*Ft^2/ac*	*Ft^3/ac*
Loblolly pine						
(1) Burn-only	40.1	5.8	4.2	737	144	3,102
(2) Burn-disk	40.2	5.9	4.2	696	136	2,894
(3) Burn-disk-bed	39.4	5.6	3.9	669	122	2,568
Means	39.9	5.8	4.1	701	134	2,855
			Prob > F-value			
Treatments (trt)	.806	.478	.392	.256	.035	.068
Linear contrasts						
Trt 1 vs. trt 2+3	.803	.763	.426	.139	.033	.058
Trt 2 vs. trt 3	.560	.257	.271	.488	.073	.125
Error mean square	3.056	.060	.148	2,717.382	80.375	66,973.974
Slash pine						
(1) Burn-only	45.9	6.2	5.4	635	137	3,402
(2) Burn-disk	45.8	6.3	5.7	556	124	3,067
(3) Burn-disk-bed	45.6	6.1	5.1	585	119	2,912
Means	45.7	6.2	5.4	592	127	3,127
		Prob > F-value				
Treatments (trt)	.959	.682	.723	.549	.029	.017
Linear contrasts						
Trt 1 vs. trt 2+3	.838	.927	1.000	.325	.012	.008
Trt 2 vs. trt 3	.851	.404	.440	.687	.356	.247
Error mean square	2.493	.202	1.050	9,718.988	50.174	29,138.913
Combined species analysis						
			Prob > F-value			
Species	< .001	.012	.001	.004	.060	.020
Treatments (trt)	.837	.402	.478	.246	.001	.004
Linear contrasts						
Trt 1 vs. trt 2+3	.770	.948	.767	.099	.001	.003
Trt 2 vs. trt 3	.610	.185	.245	.977	.048	.078
Species times trt interaction	.959	.956	.899	.764	.615	.787
Error mean square	3.549	.131	.591	6,123.717	75.993	64,910.527

[a] The study area was broadcast burned before planting the second rotation of pines, but the mechanical site treatments were not reapplied at the beginning of the second rotation.

Table 2—For study 1, comparison of total height between the first and second rotations for 15-year-old loblolly and slash pine

Rotations and site preparation treatments[a]	Total height: Loblolly pine	Total height: Slash pine
	---------- *Feet* ----------	
First rotation		
(1) Burn-only	50.6	48.7
(2) Burn-disk	53.4	48.6
(3) Burn-disk-bed	52.6	50.4
Second rotation		
(1) Burn-only	40.1	45.9
(2) Burn-disk	40.2	45.8
(3) Burn-disk-bed	39.4	45.5
	Prob > F-value	
Rotation	< .001	.007
Main effect error mean square	3.034	1.690
Treatment	.217	.673
Rotation times treatment interactions	.184	.459
Subplot effect error mean square	2.419	3.126

[a] The study area was broadcast burned before planting the second rotation of pines, but the mechanical site treatments were not reapplied at the beginning of the second rotation.

Data Analysis

For study 1, treatment and species comparisons for per pine d.b.h., height, and volume, as well as stand stocking, basal area, and yield after the second rotation were made by analyses of variance using randomized complete block design models (a = 0.05) (Steel and Torrie 1980). Fifteenth year height comparisons were made between the two rotations by analysis of variance using a split-plot-in-time model with rotation as the main plot effect and site preparation as the subplot effect (Haywood and Tiarks 1995). For study 2, pine height results were analyzed by a split-plot randomized complete block design model with site preparation as the main plot and P and N fertilization as the subplot effects (a = 0.05) (Steel and Torrie 1980). We also report probabilities > F-value (Prob) of over 5 percent but < 15 percent because natural variation is always an issue in field studies regardless of the care taken to reduce it (Peterman 1990, Thomas 1997) and this added information may be of interest to the reader.

RESULTS

In study 1, 15-year-old loblolly pine basal area per acre was significantly greater on the burned-only plots (144 ft^2 per acre) than on the two mechanical treatments (129 ft^2 per acre) (table 1). Yield was greater on the burned-only plots (3,102 ft^3 per acre) than on the two mechanical treatments (2,731 ft^3 per acre) at Prob = 0.06. Bedding as a secondary treatment following flat disking further reduced loblolly pine basal area (122 ft^2 per acre) and volume (2,568 ft^3 per acre) compared to flat disking alone (136 ft^2 per acre and 2,894 ft^3 per acre) at Prob = 0.07 and 0.12, respectively.

Fifteen-year-old slash pine basal area and yield were both significantly greater on the burned-only plots (137 ft^2 per acre and 3,402 ft^3 per acre) than on the two mechanical treatments (122 ft^2 per acre and 2,989 ft^3 per acre) (table 1). There were no important differences in slash pine growth-and-yield between the two mechanical treatments.

When the two pine species were compared, the 15-year-old slash pine had significantly greater total height, d.b.h., and volume per tree than loblolly pine after two rotations (table 1). There were significantly fewer slash pine than loblolly pine, but the slash pine stands (3,127 ft^3 per acre) still had greater yields than the loblolly pine stands (2,855 ft^3 per acre).

When site treatments were compared with both pine species in the analyses, basal area and yield were both significantly greater on the burned-only plots (141 ft^2 per acre and 3,252 ft^3 per acre) than on the two mechanical treatments (125 ft^2 per acre and 2,860 ft^3 per acre) (table 1). Bedding after flat disking significantly reduced pine basal area (121 ft^2 per acre) compared to flat disking alone (130 ft^2 per acre). It also resulted in less yield (2,740 ft^3 per acre) when compared to flat disking (2,981 ft^3 per acre) at Prob =

Table 3—For study 2, comparison of total height of 15-year-old slash pine after the second rotation

Site preparation treatments	P	N[a]	Total height
	- - *Lb/ac* - -		*Feet*
(1) Burn-only[b]	0	0	50.0
	0	50	48.6
	88	0	53.3
	88	50	54.2
(2) Burn-disk[b]	0	0	46.2
	0	50	47.3
	88	0	51.9
	88	50	48.8
(3) Burn-bed[b]	0	0	47.3
	0	50	44.1
	88	0	48.8
	88	50	49.4
			Prob > F-value
Treatment			.284
Main effect error mean square			46.053
Phosphorus			< .001
Nitrogen			.278
Phosphorus times nitrogen interaction			.681
Treatment times phosphorus interaction			.833
Treatment times nitrogen interaction			.834
Subplot error mean square			7.127

[a] Lime was applied at 1,000 lb per acre in the first rotation only. The N fertilizer treatment was applied only in the second rotation at the beginning of the eighth growing season.

[b] The study area was broadcast burned before planting the second rotation of pines, but the mechanical site treatments were not reapplied at the beginning of the second rotation.

0.08. There were no significant species-by-treatment interactions.

Both pine species were significantly taller in the first rotation (table 2), as reported at younger ages by Haywood (1994) and Haywood and Tiarks (1995). Loblolly and slash pines averaged 52 and 49 ft tall in the first rotation and 40 and 46 ft tall in the second, respectively. There were no rotation-by-treatment interactions.

In study 2, P fertilization significantly increased slash pine total height. The fertilized 15-year-old slash pines averaged 51 ft and the unfertilized pines averaged 47 ft (table 3). Nitrogen fertilization and mechanical site preparation did not significantly influence slash pine total height. There were no significant interactions.

DISCUSSION

At study 1, mechanical site preparation in the early 1960s adversely affected loblolly and slash pine basal area and yields 38 years later, and planting on old beds also adversely affected the productivity of loblolly pine but not slash pine. At study 2, slash pine was also not adversely affected by planting on old beds.

Interestingly, loblolly pine is more responsive to planting on newly created beds than slash pine on silt loam soils in the west Gulf Coastal Plain (Haywood and others 1990). Perhaps as the beds become smaller due to erosion of the crown and filling of the furrow, loblolly pine no longer enjoys the benefit of better drained soil for root growth compared to flat areas, although the negative effects of bedding on surface drainage remain (Haywood 1995). These effects may limit loblolly pine growth more than slash pine growth (Haywood and others 1990).

Also, where pine roots tended to concentrate in the beds, the trees might have drawn down nutrient reserves during the first rotation. On silt loam soils in the west Gulf Coastal Plain, loblolly pine is more sensitive to P deficiencies than slash pine (Tiarks and Shoulders 1982). A differential reduction in nutrients in the beds versus the flat areas may partly explain why loblolly pine did less well on old beds than slash pine.

Loblolly pine was somewhat more productive than slash pine at the end of the first rotation at study 1 (Haywood 1983), but the opposite was true in the second rotation (table 1). Indeed, we report a general decline in height growth for both pine species in the second rotation at study 1. Because loblolly pine needs more P on poorly drained soils than slash pine (Tiarks and Shoulders 1982), and as P is lost in harvesting and burning, a more severe growth decline occurs for loblolly pine than for slash pine (Haywood and Tiarks 1995). Planting on old beds worsens this.

Fertilization is a way to improve growth or to overcome nutrition deficiencies on Paleudult soils (Haywood and Tiarks 1990, Jokela and others 2000) and at study 2, P fertilization significantly increased slash pine yields in the first rotation (Tiarks 1983) as well as total height in the second rotation (table 3). Based on these results, we recommend P be applied to Paleudult soils at the beginning or early in the rotation on intensively managed southern pine plantation sites. Bedding is not recommended on somewhat poorly drained and better drained sites because it is usually ineffective and can create long-term management problems (Derr and Mann 1977, Haywood 1995, Haywood and others 1990). Where old beds are found, they should be either leveled or recreated and P fertilizer applied before planting loblolly pine.

LITERATURE CITED

Baldwin, V.C., Jr.; Feduccia, D.P. 1987. Loblolly pine growth and yield prediction for managed west gulf plantations. Res. Pap. SO-236. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 27 p.

Derr, H.J.; Mann, W.F., Jr. 1977. Bedding poorly drained sites for planting loblolly and slash pines in southwest Louisiana. Res. Pap. SO-134. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 5 p.

Haywood, James D. 1983. Response of planted pines to site preparation on a Beauregard-Caddo soil. In: Jones, Earle P., ed. Proceedings of the second biennial southern silvicultural research conference; 1982 November 4–5; Atlanta. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 14–17.

Haywood, James D. 1994. Early growth reductions in short rotation loblolly and slash pine in central Louisiana. Southern Journal of Applied Forestry. 18(1): 35–39.

Haywood, James D. 1995. Responses of young slash pine on poorly drained to somewhat poorly drained silt loam soils to site preparation and fertilization treatments. Res. Note SO-379. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 5 p.

Haywood, James D.; Tiarks, Allan E. 1990. Eleventh-year results of fertilization, herbaceous, and woody plant control in a loblolly pine plantation. Southern Journal of Applied Forestry. 14(4): 173–177.

Haywood, James D.; Tiarks, Allan E. 1995. Growth reductions in short-rotation loblolly and slash pines in central Louisiana—10th year results. In: Edwards, M. Boyd, comp. Proceedings of the eighth biennial southern silvicultural research conference; 1994 November 1–3; Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 268–274.

Haywood, James D.; Tiarks, Allan E.; Shoulders, Eugene. 1990. Loblolly and slash pine height and diameter are related to soil drainage in winter on poorly drained silt loams. New Forests. 4: 81–96.

Jokela, Eric J.; Wilson, Duncan S.; Allen, James E. 2000. Early growth responses of slash and loblolly pine following fertilization and herbaceous weed control treatments at establishment. Southern Journal of Applied Forestry. 24(1): 23–30.

Lohrey, Richard E. 1985. Stem volume, volume ratio, and taper equations for slash pine in the west gulf region. In: Shoulders, Eugene, ed. Proceedings of the third biennial southern silvicultural research conference; 1984 November 7–8; Atlanta. Gen. Tech. Rep. SO-54. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 451–459.

Peterman, Randall M. 1990. Statistical power analysis can improve fisheries research and management. Canadian Journal of Fisheries and Aquatic Sciences. 47: 2–15.

Pritchett, W. L.; Gooding, J.W. 1975. Fertilizer recommendations for pines in the southeastern Coastal Plain of the United States. Agric. Exp. Stn., Inst. of Food and Agric. Sci. Bull. 774. Gainesville, FL: University of Florida. 23 p.

Shoulders, Eugene; Tiarks, Allan E. 1980. Fertilizer fate in a 13-year-old slash pine plantation. Soil Science Society of America Journal. 44(1): 1085–1089.

Shoulders, Eugene; Tiarks, Allan E. 1983. A continuous function design for fertilizer rate trials in young pine plantations. In: Jones, Earle P., ed. Proceedings of the second biennial southern silvicultural research conference; 1982 November 4–5; Atlanta. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 352–356.

Steel, Robert G.D.; Torrie, James H. 1980. Principles and procedures of statistics. 2d ed. New York: McGraw-Hill. 633 p.

Thomas, Len. 1997. Retrospective power analysis. Conservation Biology. 11(1): 276–280.

Tiarks, A.E.; Haywood, J.D. 1996. Site preparation and fertilization effects on growth of slash pine for two rotations. Soil Science Society of America Journal. 60: 1654–1663.

Tiarks, A.E.; Shoulders, E. 1982. Effects of shallow water tables on height growth and phosphorus uptake by loblolly and slash pines. Res. Note SO-285. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 5 p.

Tiarks, Allan E. 1983. Effect of site preparation and fertilization on slash pine growing on a good site. In: Jones, Earle P., ed. Proceedings of the second biennial southern silvicultural research conference; 1982 November 4–5; Atlanta. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 34–39.

LOBLOLLY PINE GROWTH 13 YEARS AFTER FOUR SITE PREPARATION TREATMENTS

John C. Adams and Clyde Vidrine[1]

Abstract—Thirteen-year growth results of 1-0 planted loblolly pine seedlings (*Pinus taeda* L.) on differently prepared upland mixed pine-hardwood sites located in north western Louisiana are presented. The study was designed as a randomized complete block consisting of three blocks of four site preparation treatments, which included: chop and burn, windrow, fuelwood harvest, and fuelwood harvest followed by an application of herbicide. Thirteen-year-growth results of the planted pine show no significant height differences but highly significant diameter differences ($P < 0.01$). Mean height varied from 40 feet for the fuelwood treatment to maximum of 43 feet for the windrow treatment. Mean diameter varied from 5.3 for the fuelwood and the fuelwood/herbicide treatments to a maximum of 6.9 inches for the chop and burn site preparation treatments which was significantly different. The initial performance of the stands change over time and the potential gains by using herbicides to control hardwoods and by using genetically improved seedlings was lost because of high plantation density and pine on pine competition.

INTRODUCTION

In 1984 a study was initiated to evaluate the effects of four site preparation treatments on the soil chemical and physical properties and on the influence of competing vegetation on initial loblolly pine growth. The treatments were chop and burn (CB), windrow (WR), fuelwood harvest (FW), and fuelwood harvest followed by an application of two gallons per acre of Garlon herbicide (FW/H). The early results of the treatments on soil variables and pine growth were reported by Slay and others (1987), Slay and others (1987b) and Lockaby and others (1988), and generally reinforced conventional wisdom about these site preparation methods. The treatments with the most traffic such as the pile and windrow had the most compaction followed by the chop and burn. The fuelwood had the most competing vegetation whereas fuelwood/herbicide had the least competing vegetation. The concentrations of potassium, calcium, magnesium, and organic matter generally followed the pattern of the vegetation (fuelwood > chop and burn = windrow > fuelwood/herbicide).

During the last 15 years there has been an evolution of site preparation techniques. The use of the pile and windrow and chop and burn are out of favor and are rarely used today in this region. Fuelwood harvests, as was done in this study, are also rarely done. However, intensive utilization of the material in our forest sites resembles this technique. The use of herbicide to control woody vegetation was in its infancy, and in the time since the application of this treatment in this study, new herbicides and application techniques have been developed and employed. Since several of these site preparation techniques used 15 years ago are no longer considered the technique of choice, why then should we look at this older study? The purpose of this study is to revisit a 15-year-old study site to see if the early growth results had been sustained to the first thinning and determine effectiveness of various site treatments in producing wood. Also, if there were differences in production patterns at age 14 from the one and the three-year growth results, an attempt to explain the deviation from the expected and actual measured juvenile growth performance was made.

METHODS

The study area, located in northwest Louisiana, is characterized by a warm and humid climate. The themic temperature regime features a mean annual range from 59-72^{0}F, and average precipitation is 56 inches per year (Newton 1972). Two soil series occur throughout the area. The Gore series, a Vertic Paleudalf, composes 0-75 percent of the site; the remaining 25-35 percent consists of the Kolin series, a Haplic Glossudalf. These soils are associated with secondary terraces of the Red River. The site is homogeneous with respect to soil texture, slope and aspect. Slope ranges from 1-5 percent.

During the summer of 1983 a stand of loblolly pine approximately 40 years old was removed from the site. In the summer of 1984 four site-preparation treatments were arranged in a randomized complete block design consisting of three blocks. The treatments were chop and burn (CB), windrow (WR), fuelwood harvest (FW), and fuelwood harvest followed by an application of two gallons per acre of Garlon 4 herbicide (FW/H). The fuelwood harvest is equivalent to a whole-tree chipping operation and was sometimes used in lieu of site preparation during this period. The CB treatment consisted of a single pass with a drum chopper (pulled by a bulldozer) followed by a broadcast burn. The WR treatment was composed of a shearing

[1]Professor Forest Genetics, School of Forestry, Louisiana Tech University, Ruston, Louisiana 71272; Professor Forestry Mechanization, School of Forestry, Louisiana Tech University, Ruston, Louisiana 71272, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Third year ground line diameter and height of loblolly pine saplings planted on four different site preparation treatments

Treatment	Ground line Diameter	Total Height
	in	ft
Fuelwood/ Herbicide	2.4a	9.6a
Chop&burn	2.1b	8.6b
Windrow	1.8c	8.4b
Fuelwood	1.7c	8.1b

Means followed by the same letter are not significantly different at the P < 0.05 probability level.

operation combined with piling of sheared material into windrows. The windrow piles were outside the treatment areas, thus the treatment plots where not affected by the debris pile nor increased nutrient levels that may result from concentrations of displaced soil and pile and burned biomass. All site preparation treatments were done during the first week of July 1984. All plots were planted (6x8 foot spacing) the following winter (January 1985) with 1-0 loblolly pine seedlings genetically selected for this site. Treatment plots were one acre in size and the measurement plots were 1/10 acre and located in the center of each treatment plot.

In 1989 the site was revisited to see if the initial growth results were still as they were after the first year, and to evaluate the competing vegetation on the different site preparations. Trees within the 1/10-acre measurement plots were measured for diameter (ground line) and height, and within each measurement plot, samples of herbaceous and woody competing vegetation were taken from three randomly placed 1/1000-acre sample plots. Plant samples were oven-dried and weighed.

In September 1999 the 1/10 acre measurement plots were measured for height and diameter (DBH). Volume was calculated using the formula $0.002678D^2 H$ (Baldwin and Feduccia 1991). Analysis of variance (SAS 1985) was conducted to determine significance and Duncan's multiple range test was used to separate the means.

RESULTS AND DISCUSSION

The measurements in 1989 showed the same general pattern as the first year results reported by (Lockaby 1988). The first year results for diameter (GLD) were ranked FW/H = CB = WR > FW with the FW significantly ($P < 0.05$) smaller. The height was not significantly different. The three year results were ranked FW/H > CB > WR = FW with the fuelwood with herbicide treatment significantly ($P < 0.05$) larger in GLD and in height (table 1).

The measurements at year 14 (1999) showed a marked change in the ranking for diameter (DBH). The ranking was CB = WR > FW = FW/H or a complete change from what was the best initial performing treatment/seedling combination (FW/H) to being the worst. The CB and WR treatments were significantly ($P < 0.05$) different from the fuelwood and fuelwood with herbicide. There was no difference in total height (table 2).

When the 1999 measurements were being planned and the earlier work reviewed, the assumption was made that the fuelwood with herbicide would be the most effective treatment because of the initial control of competing hardwood vegetation and the past early seedling performance on these sites. However, this was not the case and in the interim the other site preparation treatments were, over the last 10 years, more effective from a diameter standpoint, and the fuelwood with herbicide was ranked last and significantly smaller in diameter than the other treatments.

When measurements at age three were taken, the herbaceous and woody biomasses were also sampled. At that time there was no difference in herbaceous material between the treatment plots. Woody biomass (hardwood sprouts) was significantly less ($P < 0.05$) in the WR treatment plots but the other site preparation treatments had the same woody competition. This was a change from the first year results (Lockaby and others 1988) where the fuelwood with herbicide plots had considerably less competing woody material with the other treatments statistically the same. Although this change in competing woody material had occurred by the end of the third growing season, it was not reflected in the total growth measured in each treatment. However, between year three and fourteen the effect of the herbicide was gone and the growth pattern of other treatments including the FW with no additional site work (essentially a check) were as good or better than the FW/H site preparation. The two older, more traditional site

Table 2—Fourteen-year diameter (DBH) and height of loblolly pine trees planted on four different site preparation treatments

Treatment	DBH	Total Height	Volume Per Tree
	in	ft	cuft
Chop&Burn	5.8	41.5	4.0a
Windrow	5.6a	41.0a	3.7a
Fuelwood	5.3b	41.0a	3.4bc
Fuelwood/ Herbicide	5.3b	40.5a	3.2c

Means followed by the same letter are not significantly different at the $P < 0.05$ probability level.

preparation treatments (WR and CB) had produced the largest diameters. The total height was the same across the treatments.

Historically, looking at the development of this stand there are two reasons that may explain why the seedlings given the early advantage of freedom from competition did not maintain this advantage. They are planted pine seedling numbers and planted pine domination of the site.

The stand was planted on a 6X8 spacing (Slay 1986), which is 908 seedlings per acre. These seedlings were genetically improved, and family mixes tested to perform well on the soil types at the planting site were used. The survival was 94 percent at the end of the first year or 850 trees per acre. At age three the survival was essentially unchanged. After age three the crowns began to close and competition became more and more intense with each additional years growth. The close spacing, high survival and fast growth of the planted pine completely dominated the stands with little but planted pine remaining when year 14 measurements were made. Wild pine seedlings and hardwood observed in the early years of the stand were in the overtopped position and essentially were not a factor in the stand.

The planted pine spacing is another matter. The planted pine on planted pine competition has been very intense in the treatment stands. Early fast growth and crown closure negated any advantage of one site treatment over the other. When the 14 year measurements where taken, there were still 762 trees per acre and any advantages given early by cultural treatments or by the use of genetically superior planting stock were lost in the competition among high populations of planted trees. The trees in the treatments having the best early results quickly closed canopy and slowed growth allowing the other treatments to catch up and in some cases exceed the total growth after 14 years. At age 14 the trees in all treatments plots were in less than desirable physical condition based on observations of crown percent and general fullness of the crown indicating severe competition for several years.

The lesson to be learned from this study is that the advantages of using cultural practices and improved genetic planting stock can be quickly diminished by the presence of large seedling/sapling/tree numbers. Trends that appear to be positive initially may not be maintained with high numbers of trees. Adjustment of tree numbers at planting or early in the rotation of the stand is important to keep the stand growing at its potentional. Ignoring this can, as is the case in this study, reduce severely the potential of an adequate or any return on a cultural or genetic investment. This study may be unusual in that the survival was very high but it indicates the importance of control of competition not only from hardwoods or wild pine but control of competition of the trees that we plant. Without being relatively "free to grow", investments early in the stand life may be ineffective.

ACKNOWLEDGMENTS

This project was supported by McIntire-Stennis Cooperative Forestry research program under Public Law 87-788. Study sites were provided by Willamette Industries, Ruston, LA.

REFERENCES

Baldwin, Jr.; V. C.; D. P. Feduccia. 1991. Compatible tree-volume and upper-stem diameter equations for plantation loblolly pines in the West Gulf Region. Southern Journal of Applied Forestry. 15(2): 92-96.

Lockaby, B.G.; J. M. Slay; J.C. Adams; C.G. Vidrine. 1988. Site preparation influences on below ground competing vegetation and loblolly pine seedling growth. New Forest. 2: 131-138.

Newton, M.B. 1972. Atlas of Louisiana. Louisiana State University, Baton Rouge, LA. Pub. 71-1.

SAS Institute Inc. 1995. SAS user's guide: statistics, version 5 edition. Cary, NC. 956 p.

Slay, J.M. 1986. Influences of site preparation on forest soil Chemical and physical properties, competing vegetation, and pine seedling growth in the Southern Coastal Plain. MS Thesis, College of Life Sciences, Louisiana Tech Univ. 36 p.

Slay, J. M; B.G. Lockaby; J.C. Adams; C.G. Vidrine. 1987. Effects of site preparation on soil physical properties, growth of loblolly pine, and competing vegetation. Southern Journal of Applied Forestry. 11(2): 83-86.

Slay, J. M.; B.G. Lockaby; J.C. Adams; C.G. Vidrine. 1987b. Influences of site preparation on forest soil chemical properties in the Southern Coastal Plain. Journal of Soil and Water Conservation. 42(5): 373-376.

HEIGHT RESPONSE TO HARVESTING INTENSITY AND SITE PREPARATION IN FOUR YOUNG LOBLOLLY PINE PLANTATIONS

Thomas J. Dean and Ray A. Newbold[1]

Abstract—A study was conducted to analyze the general effects of harvesting intensity and postharvest treatments on the average, three-year height of loblolly pine (*Pinus taeda* L.). This was accomplished by analyzing treatment effects across four study sites by treating the locations as random effects in the statistical model. Whole-tree harvesting using conventional methods had no distinguishable effect on the three-year average height. The main effect of bedding on height was not significant, but within the hand-felled harvest treatment, it significantly reduced height growth 0.12 meter. Herbaceous weed control increased three-year average height by 0.26 meter, and its effect on height was greater when the previous stand was harvested by conventional methods. Fertilization was the only treatment that increased three-year average height and did not interact with harvesting intensity. Across both harvesting treatments, fertilization increased three-year average height by 0.36 meter. Based on this analysis, effects observed here should be applicable to other similar sites across the Southeast.

INTRODUCTION

A study was initiated in 1993 to evaluate the impacts of the compaction and biomass removal associated with timber harvesting on the growth of the next plantation planted on that site. One of the goals of this study named Cooperative Research in Sustainable Silviculture and Soil Productivity, or CRiSSSP for short, is to evaluate this impact in as near of an operational setting as can be achieved while maintaining statistical control of treatments. Consequently, compaction as a treatment effect is the increase in bulk density and soil strength that harvesting equipment produced while moving across the site, and biomass removal as a treatment effect is the biomass intentionally or unintentionally moved from the site during harvesting. The actual treatments in this study are conventional, whole-tree harvesting with saw shears and grapple skidders and hand felling and lifting out only the merchantable portion of the stem. The movement of harvesting equipment across the site and the different removal restrictions produced differences in soil compaction and biomass removal that were measured after the harvest. This study contrasts the USDA Forest Service Long-term Study where compaction and biomass removal are directly and quantitatively manipulated (Powers and Avers 1995). Site preparation practices are included in this study to investigate their impact on growth, their role in correcting detrimental harvesting impacts, as well as their possible interaction with harvesting intensity.

This basic study has been replicated on four sites across the southeastern United States (table 1), and tree height has been measured annually for at least three years at each location. This creates the opportunity to evaluate the general impact of harvesting intensity and site preparation on early growth of newly established loblolly pine (*Pinus taeda* L.) plantations. By treating the various sites as random locations, any of these treatments that produce a change in height is evidence that the effect would occur at any random location across the Southeast. The objective of this paper is to determine whether general statements are possible concerning the effect of harvesting intensity, bedding, fertilization, and herbaceous weed control within the first three-years of height growth in loblolly pine plantations in the Southeast.

METHODS

At each study location, harvest intensity is factorially combined with bedding, fertilization, and herbaceous weed control. The combinations with the site preparation and early cultural treatments is incomplete because not all of the postharvest treatments were applied at each location. Each postharvest treatment was used at two locations at a minimum, however (table 2). Each study location was blocked according to soil type and drainage, and the treatments randomly assigned to 14 x 14 tree plots, each covering approximately 0.15 hectare. Three years of annual height measurement on 100 trees within each plot and location were analyzed using a linear model that mixed fixed and random effects (Littell and others 1966). The study locations and blocks within locations were considered random.

Exact postharvest treatment protocols varied by location. Complete descriptions are given by Wang and others (in press). Each site received an aerial application of imazapyr mixed with either triclopyr or glyphosate for minimum competition control. Bedding was performed with a single pass of two 85-centimeter disc pulled behind a tractor. Herbaceous weed control consisted of spraying a mixture of imazapyr and sulfometuron in a 1.2-meter band over the top of the seedlings. Fertilization consisted of either broadcast application of diammonium phosphate at 250

[1]Associate Professor, School of Forestry, Wildlife, and Fisheries, LSU Ag Ctr, Baton Rouge, LA 70803; Professor, School of Forestry, Louisiana Tech University, Ruston, LA 71272, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Locations and characteristics of study sites (all sites have a mean July temperature of 27°C)

Location	soil series	soil subgroup	Average Rainfall (mm)
Fred, TX	Kirbyville	Oxyaquic Paleudult	1360
Bryceland, LA	Mahan	Typic Hapludult	1370
Pine Grove, LA	Toula	Typic Fragiudult	1680
Bainbridge, GA	Hornsville	Aquic Hapludult	1670

kilogram/hectare or a complete fertilizer with micronutrients banded around each seedling. All seedlings were hand planted.

RESULTS AND DISCUSSION

Analysis was performed on all main effects and selected interactions in order to obtain interpretable results. The only treatment that did not interact with harvest intensity was fertilization (table 3). During the first three years of growth after treatment, fertilization significantly increased height growth by an average of 0.36 meter.

Both bedding and herbaceous weed control interacted with harvest intensity in their effects on average, three-year height. Bedding caused a significant reduction in height where the previous stand was hand-felled and removed by lifting the boles from the plot, and it had no effect on the average, three-year height where the previous stand was harvested by conventional means (figure 1a). The negative effect of bedding on height in the hand-felled plots was probably due to debris that was incorporated into the beds. During dry summers, this would reduce the moisture holding capacity of the beds as well as tree growth. With little or no debris in the beds, tree growth was unaffected.

Table 2—Distribution of treatments between study sites

Location Treatment	Fred TX	Bryceland LA	Pine Grove LA	Bainbridge GA
Harvest intensity	X	X	X	X
Fertilization	X			X
Bedding	X		X	
Herbaceous weed control	X	X	X	

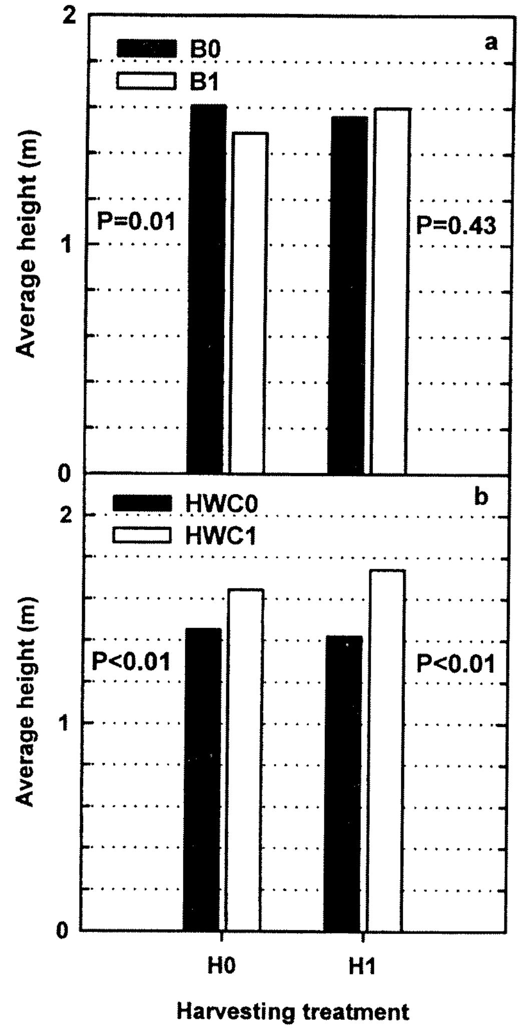


Figure 1—Interaction of harvesting intensity with bedding (a) and with herbaceous weed control (b) on three-year average height. B0 and B1 are not bedded and bedded; HWC0 and HWC1 are not sprayed for herbaceous weed control and sprayed; and H0 and H1 are hand-felled boles only harvesting and conventional, whole-tree harvesting, respectively. P values are for bedding or herbaceous weed control effects within specific harvesting treatments.

Table 3—Statistical summary of treatment effects and selected interactions

Effect	F value	Prob > F
Harvest (H)	0.21	0.64
Fertilization (F)	82 .0	<0.01
Bedding (B)	1.35	0.25
Herbaceous weed control (HWC)	48.2	<0.01
H x F	0.59	0.44
H x B	5.89	0.02
H x HWC	3.17	0.08

Herbaceous weed control significantly increased the average, three-year height in both types of harvest. The significant interaction occurred because the difference in height due to herbaceous weed control was greater when conventional harvesting methods were used than when the stand was harvested using minimum impact techniques. The slight reduction in height that seemed to occur when the stand was harvested with conventional methods with no postharvest control of herbaceous weeds was more than compensated when plots were sprayed for herbaceous weed control.

CONCLUSIONS

These results indicate that the impacts of conventional, whole-tree harvesting do not cause deleterious effects on average height over the first three years of growth on sites similar to those used in this study. Early fertilization results in significant increases of 0.36 meter in average, three-year height. Bedding significantly reduced height when the previous stand was hand felled and had no significant effect on height after harvesting with conventional means. Herbaceous weed control significantly increased the average height growth over three years, and its effect was greater when the previous stand was harvested by conventional methods. By treating the different locations as random effects in the analysis, the results seen here would apply to sites that are similar to the site used in this study.

ACKNOWLEDGMENTS

This research was supported in part by a Challenge Cost Share grant from the USDA Southern Research Station with the participation of International Paper Company, Temple-Inland Forest Products Corporation, and Willamette Forest Industries, Inc.

REFERENCES

Littell, R.C.; Milliken, G.A.; Stroup, W.W.; Wolfinger, R.D. 1966. SAS System for Mixed Models. SAS Institute, Cary, NC. 633 p.

Powers, R.F.; Avers, P.E. 1995. Sustaining forest productivity through soil quality standards; a coordinated U.S. effort. In: Powter, C.B.; Abboud, S.A.; McGill, W.B., eds. Anthropogenic Chemicals and Soil Quality Criteria. Proceedings of a symposium. 1992 August 10-11; Edmonton, Alberta. Canadian Society of Soil Science, Brandon, Manitoba. 147-190.

Wang, Z.; Carter, M.C.; Dean, T.J. in press. Impacts of forest harvesting and site preparation on soil bulk density, soil strength, and early growth of pine seedlings. Forest Science.

DISTRIBUTION OF SLASH AND LITTER AFTER WET- AND DRY-SITE HARVESTING OF LOBLOLLY PINE PLANTATIONS

Mark H. Eisenbies, James A. Burger, Yi-Jun Xu, and Steve Patterson[1]

Abstract—Displacement of logging slash and forest floor litter in the process of harvesting can interfere with forest nutrient cycling and can modify soil climate in ways that could affect regeneration success and forest productivity. The objective of this study was to assess a visual method for estimating organic matter and slash biomass residues following a typical feller-buncher/grapple-skidder clearcut harvest. A 20 by 20 meter grid was established in six 20-year-old loblolly pine plantations, each of which was 3.2 ha in size. Pre-harvest biomass was estimated using biomass equations developed by Baldwin (1987). Post harvest slash and litter biomass remaining was measured across the grid network by making visual estimates of percent coverage for each of 4 size classes and relating that to biomass using simple linear regression. Harvest slash and litter were collected from 4 m^2 plots and weighed to estimated biomass as a function of percent cover for each size class. Heavy slash (> 2.5 cm) on the wet harvest sites had a biomass of 2.49 kg/m^2, compared to 1.89 kg/m^2 on the dry harvest sites. The amount of light slash (< 2.5 cm) was also significantly greater on the wet harvest sites, 2.47 kg/m^2, compared to that on the dry-harvested sites at 1.99 kg/m^2. Litter biomass, ~2.4 kg/ m^2, and piles, 0.7 kg/m^2, were not significantly different between sites. Visual estimation procedures provide a rough but useful estimate of biomass remaining after harvest (R^2 = 0.42 to 0.67), an extensive spatial estimate that is difficult to ascertain in any other way. The method reveals a certain amount of homogenization after harvesting. Harvesting sites when dry compared to wet results in a larger amount of displacement from the interior of a logging site. These estimates can be used to judge whether harvesting disturbance on organic residues affects stand productivity.

INTRODUCTION

The importance of maintaining site quality and productivity on intensively managed forests is important because a higher production per land unit is needed to satisfy increasing population demands for forest products. Understanding how the forest sites resist, respond to, and recover from disturbances associated with forest management practices is essential for sustaining long-term productivity.

The benefits of organic matter in soils for crop production is well known. It helps synchronize the supply and demand of various plant essential nutrients (Walle and Sims, 1999; Gressel and others, 1996), and it has a positive influence on soil water retention, hydraulic conductivity, and infiltration (Prichett and Fisher, 1987). Soil strength, structure, and morphology are also greatly affected by the amount of organic matter in the soil, which helps to bind soil particles together to form soil aggregates (Mankin et.al., 1996).

Forest management can greatly influence the amount of organic materials remaining on a forest site, and, conversely, soil organic matter will influence the response of sites to management disturbances (Sanchez, 2001; Fearnside, 1999; Dick and others, 1991; Nambiar, 1996). Therefore, it is important to understand how forest practices affect the distribution of harvest slash and litter. The purpose of this study is to evaluate a post-harvest visual biomass inventory method based on Terry and Chilingar (1955), and to compare how two harvesting methods, dry-weather and wet-weather harvesting, affects spatial distribution of organic matter.

MATERIALS AND METHODS

The study site is located near Cottageville, SC, on the Atlantic coastal plain of South Carolina. The topography is flat to gently rolling; soil parent material consists of marine and fluvial sediments deposited during the Oligocene and Pleistocene eras (Stuck, 1982). Soils are poorly to somewhat poorly drained and have an aquic moisture regime. Bt horizons limit permeability and cause perched water tables. These sites are classified by Cowardin system (Cowardin and others, 1979) as Palustrine, forested, needle leaved evergreen wetlands. Regionally, these sites are very productive, and have been managed as loblolly pine plantations for the past 50 years.

In 1992, three 20 ha, loblolly pine plantations were selected based on similar age, soil, and hydrologic conditions. These

[1]Graduate Research Assistant, Professor, Research Scientist, Department of Forestry, Virginia Tech, Blacksburg, VA; Research Soil Scientist, Westvaco Corporation, Summerville, SC, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

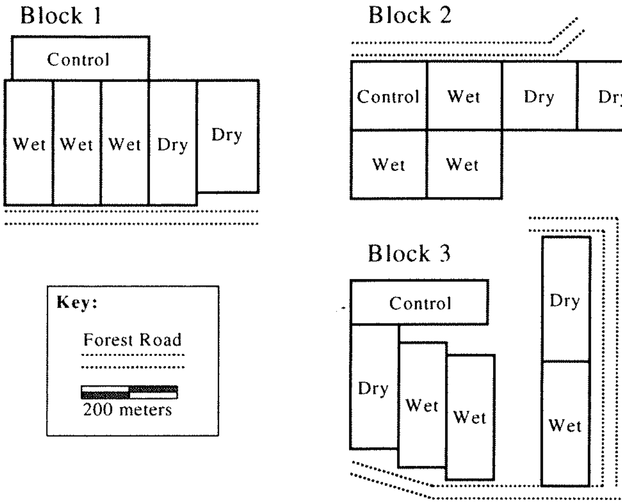


Figure 1—Block design and arrangement of treatments.

plantations (assigned as blocks) were subsequently divided into six 3.2 ha treatment plots (figure 1). Despite being contiguous within each block, each plot was treated as an individual management unit. Harvesting was conducted using conventional commercial logging operations using feller buncher/grapple skidder systems. Each plot was laid out as a separate sale and had separate decks and skid trails. In the fall of 1993, two plots on each block received a dry weather harvesting treatment. In the spring of 1994, the remaining three plots on each block were harvested during wet conditions in order to maximize soil disturbance.

Prior to harvesting, each stand was cruised for height, and diameter. Bole biomass was estimated as a function of height, diameter, and age (Baldwin, 1989). Biomass of crown components (branches and foliage) was estimated as a function of height and diameter. In addition, samples of ground litter were collected and weighed to determine biomass already present on the forest floor.

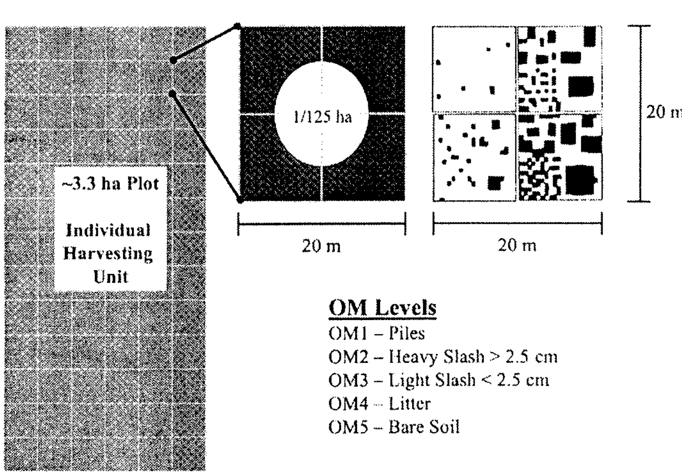


Figure 2— A 20x20 meter grid was established on each 3.3 ha plot. At each gridpoint a 1/235th ha plot was used to inventory aboveground biomass, and visual estimates were made of five classes of logging debris.

After harvesting, each stand was surveyed based on the 20x20 m grid (figure 3). Each grid location was divided into four 10x10 m quadrats in which visual estimates were made of percent cover of harvesting residue and averaged. Harvesting residues were divided into four categories: litter, light slash (<1.5 cm), heavy slash (>1.5 cm), and piles (residue > 0.3 m in depth). Visual estimates were made after a visual calibration to a reference chart (figure 2). In the case of slash piles, the depth of the piles was also measured.

After the visual assessments were completed, a subset of grid points was revisited to relate actual biomass to percent cover. A 2 by 2-m PVC frame was randomly placed in each of the four quadrats and a visual assessment was made for litter, light slash, and heavy slash. The air-dried samples were subsequently collected and weighed *in situ*. Simple linear regression was then used to predict biomass for each category based on percent cover. Regressions and statistical analyses were made at the 5 percent level using SAS procedures (SAS Institute, 1988).

An additional estimate of the biomass in piles was required because we were not able to sample them in a timely way. It was assumed that the maximum biomass of heavy slash was equivalent to the threshold level with a 0.3-m deep pile. The estimate was subsequently multiplied by depth to obtain a biomass estimate for individual slash piles.

RESULTS AND DISCUSSION

Prior to harvesting, the amount and distribution of biomass of the tree components and the litter layer were similar between the two harvesting treatments (table 1). Approximately 46 to 48 kg/m^2 was found aboveground in the form of the stem, branches, and foliage. In addition about 0.55 kg/m^2 was found in the pre-harvest litter layer. These materials had normal distributions, meaning they were heterogeneously spread throughout the site (figure 3).

Forty to sixty-five percent of the variation in post-harvest biomass was explained by our visual cover estimates (figure 4). The method tended to under-estimate biomass relative to that predicted by the Baldwin equations (figure 5); the best approximations were made for the dry harvest sites. Standing water and soil disturbances made wet visual assessments of percent cover difficult, which caused the under-estimates of biomass on the sites that were harvested when wet.

Table 1—Pre-harvest biomass of the wet and dry-harvested plots

Treatment	Aboveground Biomass (& carbon)			Pre-Harvest
	Stem	Branch	Foliage	Litter
	kg/m (kg-C/ha)			
Dry	37.63(17.08)a	4.07(1.85)a	1.83(0.83)a	0.53(0.20)a
Wet	42.50(19.30)a	4.28(1.94)a	1.86(0.84)a	0.58(0.21)a

Note: means separations compare the levels within each biomass class only.

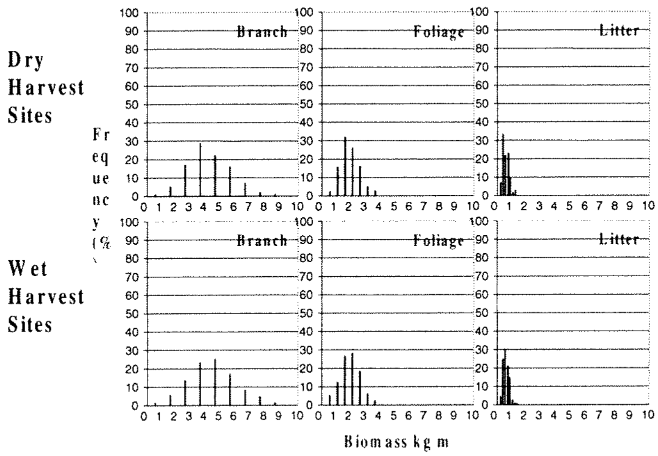


Figure 3—Pre-harvest histograms of coarse organic matter from the standing, live tree (branch and foliage), and on the ground (litter).

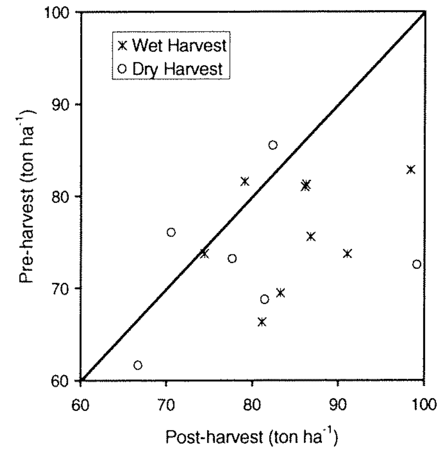


Figure 4—Linear regression plots for the four harvesting debris size classes.

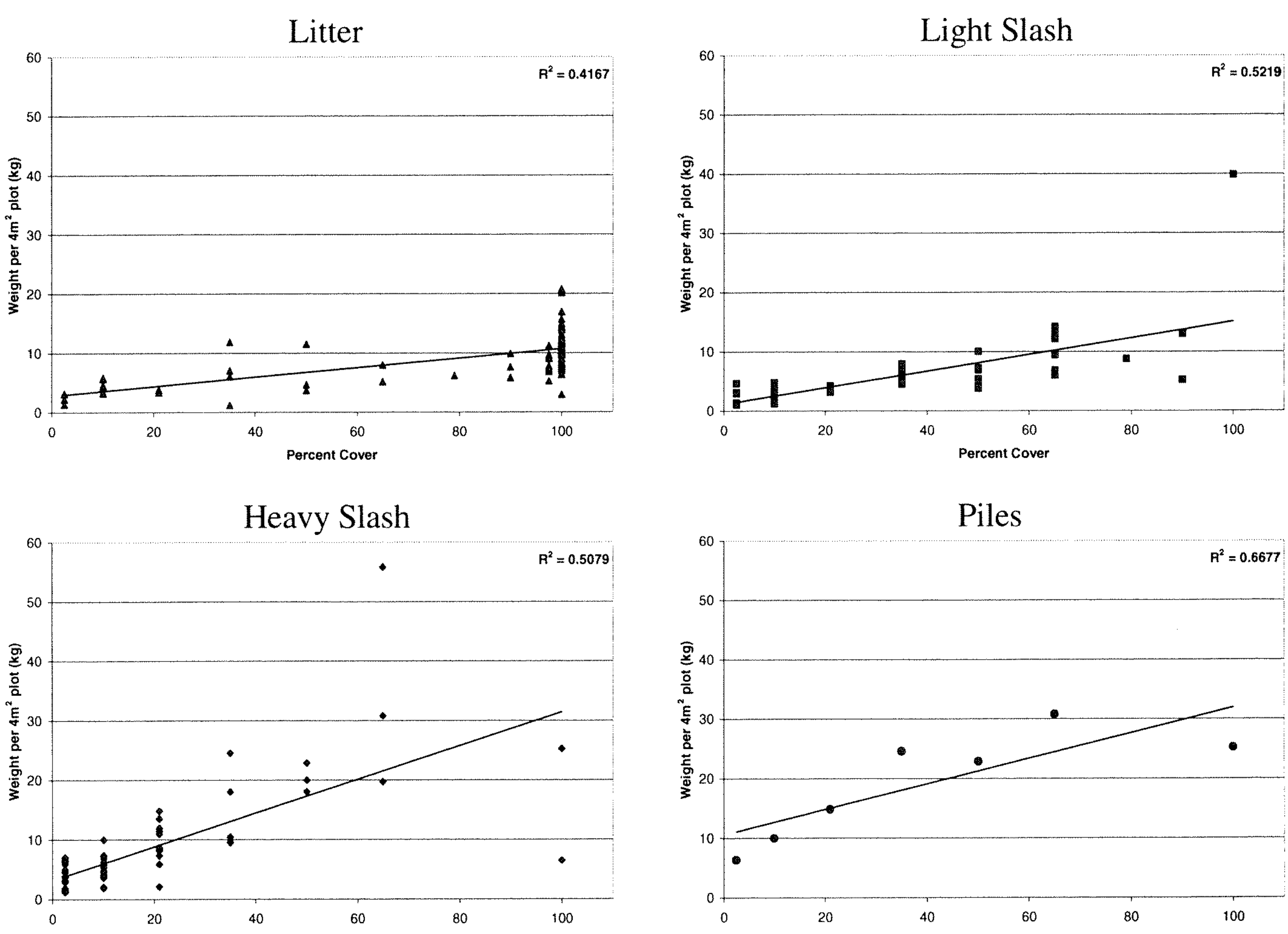


Figure 5—Comparison of pre- and post-harvest total organic matter biomass estimates.

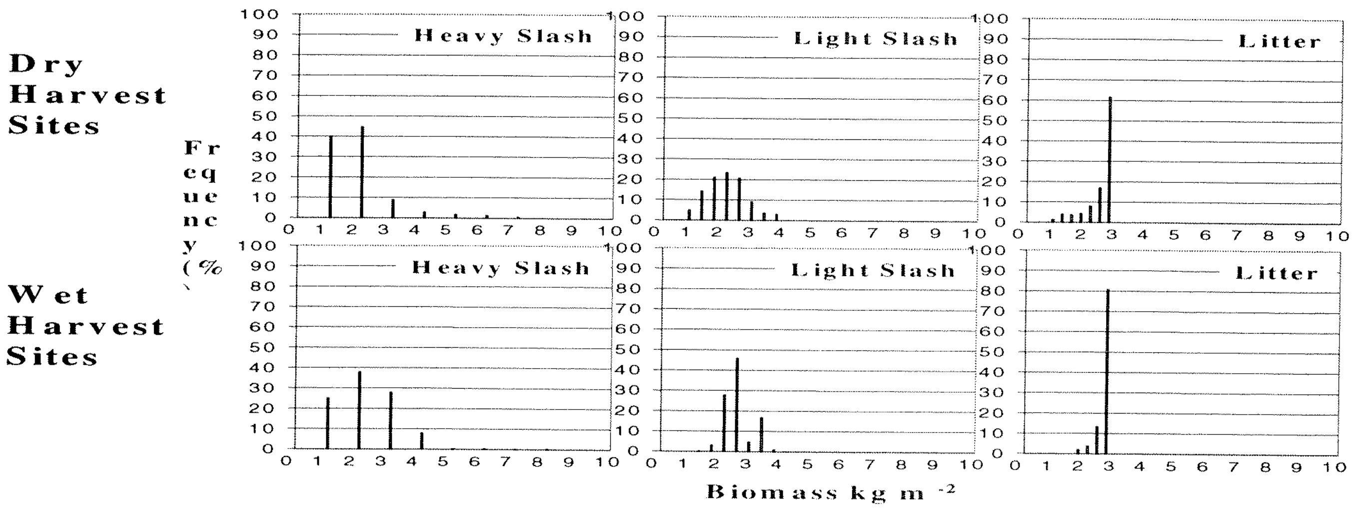


Figure 6—Post-harvest histograms of heavy slash, light slash, and litter.

Table 2—Post-harvest biomass of the wet and dry-harvested plots

Treat-ment Heavy	Slash > 2.5 cm	Light Slash < 2.5 cm	Piles Slash 1 ft deep	Litter
	kg/m (kg-C/ha)			
Dry	1.89(0.86)b	1.99(0.90)b	1.02(0.46)a	2.36(0.87)a
Wet	2.49(1.13)a	2.47(1.12)a	0.16(0.07)a	2.50(0.93)a

Note: means separations compare the levels within each biomass class only.

After harvesting, any biomass that was not removed as product was dispersed as residues across the site. A portion of the ~40 kg m^{-2} of biomass previously contained in the stems along with the 4 kg m^{-2} of biomass from the branches were repartitioned into the post-harvest categories (heavy, light slash, and piles); about 5 kg m^{-2} total for both the wet and dry harvested sites. Foliage biomass from the pre-harvest estimates were combined with the pre-harvest litter layer to form the ~2.5 kg /ha in the post harvest litter layer. Significantly more heavy and light slash was retained within the wet harvested sites (table 2). Dry sites had numerically greater biomass in piles as a result of skidding and delimbing.

Harvesting resulted in a skewed distribution of organic materials compared to pre-harvest conditions (Figure 6).

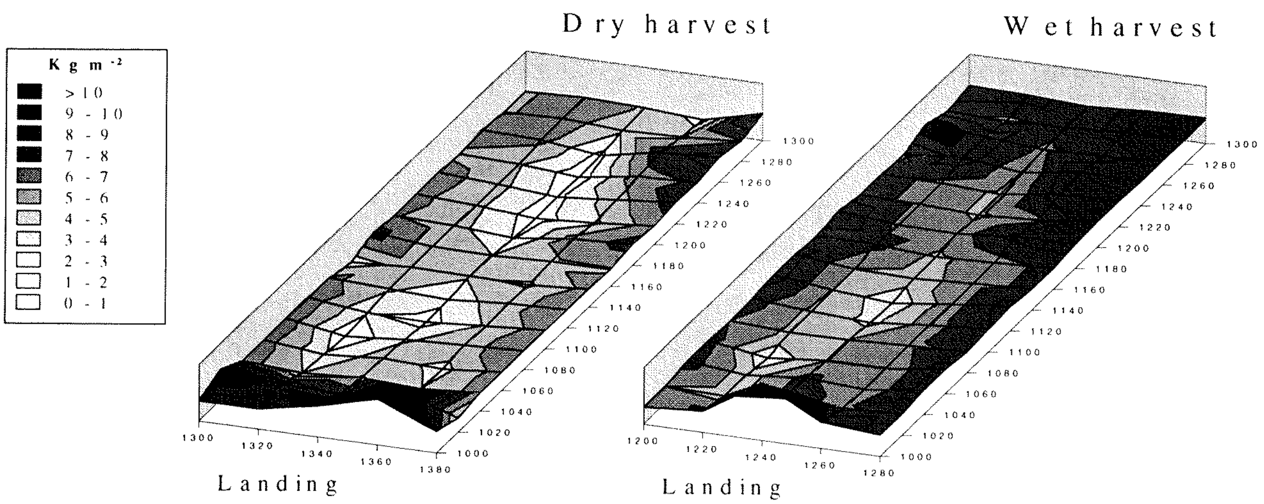


Figure 7—Post-harvest, spatial distribution of organic matter biomass for two treatment plots.

Heavy slash, which would contain components of pre-harvest branch and stem, was left-skewed, indicating that material was being homogenized into many low biomass groupings. Litter on the other hand, which contains components of pre-harvest foliage and litter, was right-skewed, indicating that material was being homogenized into many larger biomass groups.

The displacement of materials by dry-site harvesting is readily apparent in a spatial plot (figure 7). Disturbance of organic materials is minimized around the periphery of a logging site, and it is maximized where traffic is concentrated. In addition, debris are concentrated at the landings of logging sites.

CONCLUSIONS

The visual approach used in this study for estimating harvest residue biomass tends to underestimate the actual amount of residue biomass, especially on the wet-harvested sites. However, this method may be appropriate for the sites with little surface soil disturbance and standing water. Harvesting in general tended to homogenize heavy slash and litter either by skewing their distributions to the left or to the right. Residue materials were displaced to a greater extent within the interior of the plot where trafficking was the highest. At the periphery of the logging site organic materials were less disturbed.

Wet weather harvesting tended to leave a greater amount of organic debris out on the site. Logging operators topped trees where they were cut, and used those materials to support the equipment on the wet soils. As a result, organic materials were incorporated with the soil and may serve to provide a mitigating effect to soil disturbance as time passes (Kelting, 1999).

REFERENCES

Baldwin, V.C. 1987. Green and dry-weight equations for aboveground components of planted loblolly pine trees in the West Gulf Region. Southern Journal of Applied Forestry 11: 212-218.

Cowardin, L.M.; Carter, V.; Golet, F.C.; Laroe, E.T., 1979. Classification of wetlands and deepwater habitats of the United States. USDI Fish & Wildlife Serv., Washington, DC. FWS/OBS-79/31, 131 p.

Dick, W.A.; E.L. McCoy, W.M.; Edwards, R. Lal. 1991. Continuous application of no-tillage to Ohio soils. Agronomy Journal. 83(1): 65-73.

Fearnside, P.M. 1999. Forests and global warming mitigation in Brazil: opportunities in the Brazilian forest sector for responses to global warming under the "clean development mechanism". Biomass and Bioenergy. 16(3): 171-189.

Gressel, N.; J.G. McColl; C.M. Preston; R.H. Newman; R.F. Powers. 1996. Linkages between phosphorous transformations and carbon decomposition in a forest soil. Biogeochemistry. 33(2): 97-123.

Kelting, D.L. 1999. Timber harvesting and site preparation effects on soil quality for loblolly pine growing on the Lower Coastal Plain of South Carolina. Blacksburg, VA: Virginia Tech. 197 p. PhD Disertation

Mankin, K.R.; A.D. Ward; K.M. Boone. 1996. Quantifying changes ins soil physical properties from soil and crop management: A survey of experts. Transactions of the ASAE. 39(6): 2065-2074

Nambiar, E.K.S. 1996. Sustained productivity of forests is a continuing challenge to soil science. Soil Science Society of America Journal. 60: 1629-1642.

Prichett and Fisher. 1987. Properties and management of forest soils. 2d ed. New York, NY: John Wiley and Sons. 494 p.

Sanchez, F.G.; R.J. Eaton. 2001. Sequestering carbon and improving soils - Benefits of mulching and incorporating forest slash. Journal of Forestry. 99(1): 32-36.

SAS Institute Inc. 1988. SAS/STAT User's Guide, Release 6.03 Edition, SAS Institute Inc. Cary, NC, 1028 p.

Stuck, W.M. 1982. Soil survey of Colleton County, South Carolina. USDA Natural Resource Conservation Service, Washington D.C. 152p.

Terry, R.D.; G.V. Chillingar. 1955. Summary of "Concerning some additional aids in studying sedimentary formations"; by M.S. Shvetsov. Journal of Sedimentary Petrology. 25(3): 229-234.

Walle, R.J.; B.G. Sims. 1999. Fertility gradients in naturally formed terraces on Honduran hillside farms. Agronomy Journal. 91(2): 350-353.

DISKING EFFECTS ON FIFTH-YEAR VOLUME PRODUCTION OF FOUR EASTERN COTTONWOOD CLONES ESTABLISHED ON AN AFFORESTATION SITE, SHARKEY COUNTY, MISSISSIPPI

Ronald K. Fisher, Emile S. Gardiner, John A. Stanturf, and C. Jeffrey Portwood[1]

Abstract—In spring 1995, an eastern cottonwood (*Populus deltoides*) plantation was established on a former agricultural field in Sharkey County, MS to evaluate the effects of clonal variety and mechanical weed control on aboveground biomass production. Four cottonwood clones, ST-66, ST-72, ST-75, and S7C-1 were planted on a 12 foot × 12 foot spacing and subjected to 2 mechanical weed control treatments (disking in year 1 versus disking in year 1 and 2). Survival in the plantation ranged from 96 percent for ST-66 and S7C-1 to 87 percent for ST-72. But, survival was not influenced by mechanical weed control as it averaged 93 percent for each treatment level. After the fifth growing season, mean cottonwood height ranged from 48.3 feet for ST-66 to 39.8 feet for the other three clones. Similarly, diameter of ST-66 averaged 5.5 inches, while diameter of the other clones averaged 4.8 inches. Two years of mechanical weed control did not improve tree growth as heights averaged 41.8 feet and diameters averaged 4.9 inches regardless of disking treatment. Clonal effects on volume production were obvious after 5 growing seasons, ranging from 1038 feet^3 acre^{-1} outside bark for ST-66 to 574 feet^3 acre^{-1} outside bark for ST-75. Volume inside bark ranged from 631 feet^3 acre^{-1} for ST-66 to 279 feet^3 acre^{-1} for ST-75. Multiple years of mechanical weed control did not improve eastern cottonwood volume production five growing seasons after plantation establishment. Results indicate that eastern cottonwood plantations may be established to rapidly develop a forest structure on a wide range of afforestation sites in the Lower Mississippi River Alluvial Valley.

INTRODUCTION

Extensive deforestation in the Lower Mississippi River Alluvial Valley, driven primarily by land use conversion to agricultural production, reduced bottomland hardwood forest acreage by more than 75 percent in the region (Stanturf and others 2000, Sternitzke 1976). Recently, interest in restoring bottomland hardwood forests on marginally economical agricultural land has been spurred by several governmental incentive programs (Stanturf and others 1998). Although most afforestation projects in the Lower Mississippi River Alluvial Valley focus on establishing heavy mast species such as bottomland oaks (*Quercus* spp.) (King and Keeland 1999), some landowners have management objectives that require establishment of fast growing, intensively managed and economically sustainable hardwood plantations (Stanturf and Portwood 1999).

Eastern cottonwood (*Populus deltoides* Bartram ex Marshall), a native, pioneer species that thrives on alluvial soils throughout the central and eastern United States, has several attributes which make it an appealing selection for afforestation in the Lower Mississippi River Alluvial Valley (Cooper 1990). Relative to plantation establishment and development, eastern cottonwood can be propagated with vegetative cuttings, superior clones are available for a variety of site types, plantation cultural practices are well established, it exhibits extremely fast growth rates, and growth and yield models are available for the species (Cao and Durand 1991a, Krinard 1988, McKnight 1970). The suitability of this species to plantation culture has led to its establishment in fiber farms and biofuel plantations worldwide. As an example, more than 3.7 million acres of eastern cottonwood have been planted in China since its introduction in the 1970s (Cao and Conner 1999).

Although sustainable fiber production is often the driving force behind establishment of eastern cottonwood plantations, other environmental benefits can be derived through afforestation with this species. Gardiner and others (In Press) demonstrated that the understory of eastern cottonwood plantations may be suitable for facilitating establishment of other native bottomland tree species on afforestation sites. The importance of eastern cottonwood forests as habitat for game and non-game wildlife species has been established for several decades (Twedt and Portwood 1997, Wesley and others 1981, Wigley and others 1980). Thornton and others (1998) demonstrated that sediment loss in runoff from cottonwood plantations was substantially lower than runoff from fields under conventional

[1]Forestry Technician and Research Forester, USDA Forest Service, Southern Research Station, Center for Bottomland Hardwoods Research, Stoneville, MS 38776, respectively; [2]Project Leader, USDA Forest Service, Southern Research Station, Forestry Sciences Laboratory, Athens, GA 30602;[3]Operations Manager Hardwood Resources, Temple-Inland Forest Products Corporation, Diboll, TX 75941, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Schedule of operations during establishment of an eastern cottonwood plantation, Sharkey County, MS (adapted from Schweitzer and Stanturf 1999)

Date	Activity
October 1994	- Site preparation: two-pass disking - Row establishment with liquid nitrogen applied in subsoil trenches at 100 pounds acre^{-1}
March 1995	- Planted eastern cottonwood cuttings - Herbicide application: 6 foot band application of oxyfluorofen at 80 ounces acre^{-1} + glyphosate at 24 ounces acre^{-1} over dormant cuttings
May 1995	- Mechanical weed control: one-pass disking and row cultivation followed by second pass at right angles 2 weeks later
June - July 1995	- Herbicide application: basal application of oxyfluorofen in a 3 foot band at 32 ounces acre^{-1}
August 1995	- Mechanical weed control: one-pass disking and row cultivation followed by second pass at right angles 2 weeks later
Summer 1995	-Pesticide application: carbanyl applied at 16 ounces acre^{-1} for cottonwood leaf beetle control
June 1996	-Pesticide application: carbanyl applied at 16 ounces acre^{-1} for cottonwood leaf beetle control
June - July 1996	- Mechanical weed control: one-pass disking

agricultural production. Vose and others (2000) documented the potential of eastern cottonwood for phytoremediation of groundwater contaminants such as trichloroethylene. Thus, improvements in surface and ground water quality can result from rapid buildup of a litter layer and root system beneath the forest cover. Furthermore, the high productivity of eastern cottonwood makes the species attractive for carbon sequestration and biofuel purposes (Thornton and others 1998, Stanturf and others 2000).

Though cultural practices for establishment and management of eastern cottonwood plantations are well developed, there is a need to refine current management systems. This is particularly relevant to plantation establishment on former agricultural land, sites where eastern cottonwood productivity may be marginal. The purpose of this study was to evaluate effects of clonal variety and mechanical weed control on fifth-year growth and volume production of eastern cottonwood on an afforestation site in the Lower Mississippi River Alluvial Valley.

METHODS

Study Site

The study was conducted on a previously farmed site located in Sharkey County, MS (90° 44' west latitude, 32° 58' north longitude). The site is situated about 1.5 miles east of Anguilla, and immediately north of the Delta National Forest. Soil on the site was mapped as a Sharkey series (very-fine, smectitic, thermic chromic EPIAQUERTS). Annual rainfall in Sharkey County averages 52 inches, and mean temperatures range from 45° Fahrenheit in January to 82° Fahrenheit in July (Scott and Carter 1962). Cultivation of the study site for soybean (*Glycine max* [Linnaeus] Merrill) production ended in the fall of 1994.

Experimental Design

In March 1995, 3, 20-acre stands (blocks) of eastern cottonwood were established using plantation establishment procedures practiced by Crown Vantage, Incorporated (table 1). For each 20-acre stand, 4 cottonwood clones (ST-66, ST-75, ST-72, S7C-1) were planted in 5-acre plots on a 12 foot × 12 foot spacing. Each 5-acre plot was split and randomly assigned a mechanical weed control treatment level. Half of the split-plots received weed control by disking in 1995, and the other half received weed control by disking in 1995 and 1996.

In each split-plot, a 0.5-acre measurement plot was established to record survival, height and diameter growth of eastern cottonwood. Total height and diameter at breast height of surviving cottonwood stems were measured after the fifth growing season. Tree heights were measured to the nearest 0.1 foot with a Criterion 300 Survey Laser (Laser Technology, Incorporated, Englewood, CO 80112), while diameter at breast height was measured to the nearest 0.1 inch with calipers. When multiple stems originated from the same cutting, the largest stem was measured.

Data Analyses

Individual tree volume was calculated using equations developed by Krinard (1988). Total tree volume outside bark = 0.06 + 0.002221 × (diameter^2 × height), volume inside bark to a 3-inch top = -0.86 + 0.001904 × (diameter^2 × height). If diameter was less than 5.0 inches, equations published by Mohn and Krinard (1971) were substituted. Intercept and slope coefficients from Mohn and Krinard (1971) were 0.21 and 0.00221 for volume outside bark, and -0.62 and 0.00204 for volume inside bark. Volume per acre was calculated by multiplying mean survival for a clone by the mean volume inside bark or outside bark for individual

Table 2—Analysis of variance sketch for a randomized block design with split-plots used to analyze fifth year survival, height, diameter, and volume production of 4 eastern cottonwood clones

Source	Degrees of Freedom
Total	23
Block	2
Cottonwood Clone	3
Error(Cottonwood Clone)	6
Disking	1
Cottonwood Clone X Disking	3
Error	8

stems of the given clone. Basal area per acre was determined in a similar fashion. That is, mean survival for a clone was multiplied by the mean basal area of individual stems of the given clone.

Treatment effects on response variables (survival, height, diameter, volume inside bark, volume outside bark) were analyzed according to a randomized complete block design with split-plots (table 2). The analysis of variance was conducted with SAS statistical software (SAS Institute Incorporated, Cary, NC 27513). Survival percentages were transformed with a square root transformation prior to analysis. Where significant treatment effects were identified ($\alpha = 0.05$), differences between means were calculated according to procedures outlined by Petersen (1985).

RESULTS AND DISCUSSION

Stem-Level

After 5 growing seasons, none of the response variables measured in the eastern cottonwood plantation were influenced by multiple years of mechanical weed control (table 3). Survival was exceptional throughout the plantation, averaging 93 percent for each disking regime. Surviving eastern cottonwood stems averaged 41.8 feet tall and 4.9 inches diameter at breast height. Across disking regimes, stem volume averaged more than 1.4 feet^3 inside bark and 2.6 feet^3 outside bark (table 3).

Table 3—Effects of 1 year and 2 years of weed control by disking on survival, height, diameter, and volume inside bark and outside bark for an eastern cottonwood plantation, 5 years after establishment, Sharkey County, MS

Variable	Disking 1995	Disking 1995-96
Survival (pct)[a,b]	93 ± 1.4 a	93 ± 1.4 a
Height (ft)	41.5 ± 7.2 a	42.2 ± 7.0 a
Diameter (in)	4.9 ± 0.69 a	5.0 ± 0.69 a
Volume inside bark (ft^3)	1.4 ± 0.70 a	1.5 ± 0.88 a
Volume outside bark (ft^3)	2.6 ± 0.97 a	2.7 ± 1.10 a

[a] For each variable, means in rows followed by the same letter are not significantly different at =0.05.
[b] Mean ± standard error.

An early recommendation by McKnight (1970) suggested that eastern cottonwood plantations should be maintained weed-free until they develop to crown closure. More recently, Stanturf and Portwood (1999) suggested that weed control is necessary when stems average less than 6 feet tall after the first growing season, and it is not necessary when stems average greater than 8 feet tall. Benefits of additional weed control are uncertain when first-year stem height ranges between 6 and 8 feet (Stanturf and Portwood 1999). First-year sapling height in this study was on the lower end of the range of uncertainty as it averaged 6.8 feet (data not presented). Our results indicate that the additional year of weed control was not necessary for improving survival or growth of eastern cottonwood. In fact, Schweitzer and Stanturf (1999) reported that third-year growth in the current plantation was reduced by 2 years of mechanical weed control. They attributed the growth reduction to root damage during the second year of disking. Results from this study indicate that factors in addition to tree height should be considered before prescribing weed control practices. Such factors may include competition level and site quality. For example, 6 feet of first-year height growth on a marginally productive soil, such as the Sharkey series in this study, may be comparable to 10 feet of height growth on a highly productive soil such as the Commerce series (Cao and Durand 1991b). Eliminating mechanical weed control in the second year of plantation establishment could amount to savings of 10 dollars per acre.

Clonal effects on survival, height, diameter and volume production were apparent in the plantation by the end of the fifth growing season (table 4). ST-66 and S7C-1 showed 10 percent higher survival than ST-72. Survival of ST-75 was numerically intermediate, but did not differ from the other clones (table 4). On the Sharkey soil series of the study site, ST-66 outperformed all other clones in fifth year height and diameter. Average height of ST-66 was 21 percent taller than the average height of the 3 other clones. Likewise, diameter of ST-66 measured 14 percent higher than the average diameter of the 3 other clones (table 4). As expected, results on volume production by cottonwood clone tracked similar to height and diameter growth. Five years after stand establishment, ST-66 produced a greater stem volume, inside bark and outside bark, than all other clones.

Clonal effects on eastern cottonwood survival and growth are well established (Foster 1985). Results from this study indicate that early growth of ST-66 on a heavy clay soil was superior to the other tested clones. The superior performance of ST-66 would be beneficial on afforestation sites of similar soil where management objectives targeted fiber production, carbon sequestration, or development of vertical structure. However, a thorough consideration of management objectives for the afforestation site should be considered prior to clone selection. To illustrate, Goelz and Monroe (1995) presented findings from a 21-year-old eastern cottonwood clonal trial in the Lower Mississippi River Alluvial Valley. They observed that ST-66 performed well in a short rotation for fiber production, but was only average for the relatively long rotation sawtimber production. Conversely, ST-72, which exhibited average volume production in this study, was a favored sawtimber producer

Table 4—Mean survival, height, diameter, and volume inside bark and outside bark for 4 eastern cottonwood clones, 5 growing seasons after plantation establishment, Sharkey County, MS

	Clone			
Variable	ST-66	S7C-1	ST-72	ST-75
Survival (pct)[a,b]	96 ± 0.58 a	96 ± 1.3 a	87 ± 0.98 b	93 ± 2.0 ab
Height (ft)	48.3 ± 2.1 a	41.8 ± 2.4 b	40.7 ± 2.7 b	36.8 ± 2.4 b
Diameter (in)	5.5 ± 0.21 a	4.8 ± 0.25 b	5.0 ± 0.28 b	4.7 ± 0.26 b
Volume inside bark (ft^3)	2.2 ± 0.36 a	1.3 ± 0.28 b	1.4 ± 0.28 b	1.0 ± 0.17 b
Volume outside bark (ft^3)	3.6 ± 0.42 a	2.5 ± 0.36 bc	2.6 ± 0.38 b	2.0 ± 0.28 c

[a]For each variable means within rows followed by the same letter are not significantly different at =0.05.

[b] Mean ± standard error.

Table 5—Fifth year stem density, basal area and volume outside bark of 4 eastern cottonwood clones planted on a 12 foot × 12 foot spacing at an afforestation site, Sharkey County, MS

Clone	Stem Density (stems/ac)	Basal Area (ft^2/ac)	Volume (ft^3/ac)
ST-66	290	48	1038
S7C-1	290	36	712
ST-72	263	36	680
ST-75	281	34	574

at age 21 (Goelz and Monroe 1995). Additionally, eastern cottonwood productivity can be improved by establishing appropriate clonal mixes (Foster and others 1998). Establishment of extensive, single clone stands where forest restoration objectives are a focus may be inappropriate.

Stand-Level

Estimates of stand development are of primary importance to land managers with forest restoration objectives. Through 5 years of development in the eastern cottonwood plantation, stand density averaged about 280 stems/acre, basal area averaged 38 feet²/acre, and merchantable volume averaged 750 feet³/acre (table 5). In correspondence with individual stem results, variation in stand density, basal area and volume production was observed among clonal stands (table 5). Stem density ranged about 10 percent, basal area ranged about 41 percent, and volume estimates ranged more than 80 percent between clonal stands.

Stand level basal area and volume estimates observed in this study were similar to results reported by Krinard and Kennedy (1980). The study reported by Krinard and Kennedy (1980) involved 4 cottonwood clones established on a former soybean field with soil mapped to the same series as this study. Survival averaged only 75 percent, but the plantation had an average basal area of 38 feet²/acre and yielded a volume outside bark of 683 feet³/acre at year 5. Though the Sharkey soil series is considered marginally productive for eastern cottonwood (McKnight 1970), results from this study confirm the observation of Krinard and Kennedy (1980) that its exceptional growth on these heavy clay soils is unmatched by any other bottomland hardwood species. Eastern cottonwood can be used by afforestation managers to rapidly develop a forest structure on a wide range of site types of the Lower Mississippi River Alluvial Valley.

LITERATURE CITED

Cao, F. L.; Conner, W. H. 1999. Selection of flood-tolerant *Populus deltoides* clones for reforestation projects in China. Forest Ecology and Management. 117: 211-220.

Cao, Q. V.; Durand, K. M. 1991a. A growth and yield model for improved eastern cottonwood plantations in the Lower Mississippi Delta. Southern Journal of Applied Forestry. 15: 213-216.

Cao, Q. V.; Durand, K. M. 1991b. Site index curves for eastern cottonwood plantations in the Lower Mississippi Delta. Southern Journal of Applied Forestry. 15: 28-30.

Cooper, D. T. 1990. *Populus deltoides* Bartr. ex Marsh. eastern cottonwood. In: Burns, R. M.; Honkala, B. H., tech. coords. Silvics of North America: 2. Hardwoods. Agriculture Handbook 654. U. S. Department of Agriculture, Forest Service, Washington, D. C. vol. 2, 877 p.

Foster, G. S. 1985. Provenance variation of eastern cottonwood in the lower Mississippi Valley. Silvae Genetica. 13:116-118.

Foster, G. S.; Rousseau, R. J.; Nance, W. L. 1998. Eastern cottonwood clonal mixing study: intergenotypic competition effects. Forest Ecology and Management. 112: 9-22.

Gardiner, E. S.; Schweitzer, C. J.; Stanturf, J. A. In Press. Photosynthesis of Nuttall oak (*Quercus nuttallii* Palm.) seedlings interplanted beneath an eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) nurse crop. Forest Ecology and Management.

Goelz, J. C. G.; Monroe, R. L. 1995. A clonal cottonwood trial after 21 years. In: Edwards, M. B., comp. Proceedings of the eighth biennial southern silvicultural research conference; 1994 November 1-3; Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC; U. S. Department of Agriculture, Forest Service, Southern Research Station: 367-372.

King, S. L.; Keeland, B. D. 1999. Evaluation of reforestation in the Lower Mississippi River Alluvial Valley. Restoration Ecology. 7: 348-359.

Krinard, R. M. 1988. Volume equations for plantation cottonwood trees (*Populus deltoides*). Res. Note SO-347. New Orleans, LA: U. S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 4 p.

Krinard, R. M.; Kennedy, H. E. Jr. 1980. Five-year-old cottonwood plantation on a clay site: growth, yield and soil properties. Southern Journal of Applied Forestry. 4(2): 80-83.

McKnight, J. S. 1970. Planting cottonwood cuttings for timber production in the South. Res. Pap. SO-60. New Orleans: U. S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 17 p.

Mohn, C. A.; Krinard, R. R. 1971. Volume tables for small cottonwoods in plantations. Res. Note SO-113. New Orleans, LA: U. S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 4 p.

Petersen, R. G. 1985. Design and analysis of experiments. New York: Marcel Dekker, Inc. 429 p.

Schweitzer, C. J.; Stanturf, J. A. 1999. A comparison of large-scale reforestation techniques commonly used on abandoned fields in the Lower Mississippi Alluvial Valley. In: Haywood, J. D., ed. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16-18; Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U. S. Department of Agriculture, Forest Service, Southern Research Station: 136-141.

Scott, F. T.; Carter, R. C. 1962. Soil survey of Sharkey County, Mississippi. U. S. Department of Agriculture, Soil Conservation Service, 36 p.

Stanturf, J. A.; Gardiner, E. S.; Hamel, P. B.; Devall, M. S.; Leininger, T. D.; Warren, M. E., Jr. 2000. Restoring bottomland hardwood ecosystems in the Lower Mississippi Alluvial Valley. Journal of Forestry. 98: 10-16.

Stanturf, J. A.; Portwood, C. J. 1999. Economics of afforestation with eastern cottonwood (*Populus deltoides*) on agriculture land in the Lower Mississippi Alluvial Valley. In: Haywood, J. D., ed. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16-18; Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U. S. Department of Agriculture, Forest Service, Southern Research Station: 66-72.

Stanturf, J. A.; Schweitzer, C. J.; Gardiner, E. S. 1998. Afforestation of marginal agricultural land in the Lower Mississippi River Alluvial Valley, U.S.A. Silva Fennica. 32:281-297.

Sternitzke, H. S. 1976. Impact of changing land use on Delta hardwood forest. Journal of Forestry. 74: 25-27.

Thornton, F. C.; Joslin, J. D.; Bock, B. R.; Houston, A.; Green, T. H.; Schoenholtz, S.; Pettry, D.; Tyler, D. D. 1998. Environmental effects of growing woody crops on agricultural land: first year effects on erosion, and water quality. Biomass and Bioenergy. 15: 57-69.

Twedt, D. J.; Portwood, J. 1997. Bottomland hardwood reforestation for Neotropical migratory birds: are we missing the forest for the trees. Wildlife Society Bulletin. 25: 647-652.

Vose, J. M.; Swank, W. T.; Harvey, G. J.; Clinton, B. D.; Sobek, C. 2000. Leaf water relations and sapflow in eastern cottonwood (*Populus deltoides* Bart.) trees planted for phytoremediation of a groundwater pollutant. International Journal of Phytoremediation 2: 53-73.

Wesley, D. E.; Perkins, C. J.; Sullivan, A. D. 1981. Wildlife in cottonwood plantations. Southern Journal of Applied Forestry. 5: 37-42.

Wigley, T. B.; Wesley, D. E.; Perkins, C. J.; Sullivan, A. D. 1980. Use of a cottonwood monoculture by white-tailed deer. Journal of Wildlife Management. 44: 264-265.

SOIL PROFILE CHARACTERISTICS OF A 25-YEAR-OLD WINDROWED LOBLOLLY PINE PLANTATION IN LOUISIANA

William B. Patterson, John C. Adams, Spencer E. Loe, and R. Jarod Patterson[1]

Abstract—Windrowing site preparation, the raking and piling of long rows of logging debris, has been reported to displace surface soil, redistribute nutrients, and reduce volume growth of southern pine forests. Many of these studies have reported short-term results, and there are few long-term studies of the effects of windrowing on soil properties and pine growth. A 16.2 hectare tract on Sacul fine sandy loam (clayey, mixed, thermic Aquic Hapludult) in Jackson Parish in northern Louisiana was windrowed in 1975. The objective of this study is to compare soil physical and chemical properties from scraped areas between windrows with that from windrow pile soils, 25 years after windrowing. Surface, subsurface, and subsoil horizons were sampled from 13 soil profiles within inter-row (scraped) and windrow (piled) positions. Thickness of the O, A, and E horizons, as well as depth to the Bt horizon, were measured in these profiles. Comparisons were made on the following properties for each horizon on each of the two site positions: organic matter, pH, available phosphorus, and exchangeable calcium, magnesium, potassium, and sodium. Bulk density was measured for windrow and inter-row position surface and subsurface soils. Pore space and air-filled volume were calculated using bulk density and water content. Mean bulk density of windrow surface soils was 1.18 g cm^{-3}, as compared with 1.53 g cm^{-3} for inter-row surface soils. Inter-row subsurface bulk density was also significantly greater than that for windrow positions. Inter-row soils at both depths had significantly less pore space and air-filled volume than that of the windrow positions. In contrast to physical properties on the site, there were no significant differences in surface or subsurface soil chemical properties. Site index (base 50 years) of loblolly pine growing between the windrows was the same (97 feet) as that growing on a non-windrowed part of the tract. Although surface and subsurface soils between windrows were significantly compacted, this compaction does not appear to have limited loblolly pine growth. After 25 years, there was little evidence of nutrient redistribution. The effectiveness of windrowing in reducing woody competition during early stand development may be a more important factor influencing growth.

INTRODUCTION

Piling logging slash into elongated windrows is a common site preparation method in the southeastern US. The moving of slash by rakes or blades usually involves displacement of some surface soil. This displacement of surface soil has been associated with redistribution of nitrogen and phosphorus (Pye and Vitousek 1985, Tew and others 1986, Morris and others 1983) and potassium, calcium, and magnesium (Tew and others 1986, Morris and others 1983) away from the bladed or raked area, into the pile. Loss of some of the organic matter enriched surface can result in higher bulk densities, lower porosity and lower hydraulic conductivity (Tuttle and others 1985). Loblolly pine root growth was decreased with small and large increases in bulk density on sand, loam, and clay (Foil and Ralston 1967). Windrowing has been associated with lower volumes in southern pine plantations. Nineteen years after site preparation, a rootraked and windrowed area contained 187 m^3/a of loblolly pine, but a broadcast burned area had a volume of 346 m^3/ha (Haines and others 1975). Across a wide variety of soils in the deep south, Haywood and Burton (1989) found shearing and windrowing to have the lowest loblolly pine site index and volume after 12 years, as compared with five other mechanical site preparation treatments. The soil physical and chemical research on windrows and site preparation is largely focused on the few years after the treatment, with the exception of few studies. Glass (1976) found that the 2.54 cm of displaced surface soil on a 25-year old raked and piled loblolly pine plantation in the North Carolina Piedmont resulted in a 2.5 meter lower site index (50 years) versus adjacent pines in unwindrowed plantations.

The purpose of this paper is to evaluate effects of windrow site position on soil properties of a loblolly pine (*Pinus taeda* L.) plantation in the upper Coastal Plain in northern Louisiana 25 years after windrowing. The study objectives are to evaluate differences in horizon depths, soil physical properties, and soil chemical properties between windrow pile positions and inter-row (cleared) positions.

[1]Assistant Professor, Professor, Undergraduate, and Undergraduate, School of Forestry, Louisiana Tech University, Ruston, LA 71272, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Soil horizon characteristics of windrow (piled) and inter-row position soils

Variable	Windrow		Inter-Row		Pr>t
	Mean	SE	Mean	SE	
O horizon thickness, cm	2.96	0.42	3.18	0.39	0.7867
A horizon thickness, cm	23.50	4.13	13.65	1.71	0.0251
E horizon thickness, cm	23.50	5.04	14.22	2.65	0.1236
Depth to Bt, cm	46.99	1.94	29.15	2.07	0.0010

Table 2—Soil physical properties of windrow (piled) and inter-row position soils

Variable	Windrow		Inter-Row		Pr>t
	Mean	SE	Mean	SE	
Surface Bulk Density, g cm^{-3}	1.18	0.04	1.53	0.02	0.0001
Surface Pore Space, pct	54.56	1.39	41.19	0.67	0.0000
Surface Air Volume, pct	26.67	1.81	12.57	0.75	0.0001
Subsurface Bulk Density, g cm^{-3}	1.51	0.04	1.67	0.03	0.0061
Subsurface Pore Space, pct	42.01	1.55	35.96	1.21	0.0072
Subsurface Air Volume, pct	11.47	1.14	7.92	0.92	0.0277

METHODS

The study area, a 16.2 hectare tract, is located in Jackson Parish, LA, within the upper coastal plain. The entire tract is mapped as a moderately well drained Sacul fine sandy loam (clayey, mixed, thermic Aquic Hapludult). The tract was sheared and windrowed after harvesting in 1975. The windrows were burned but not planted to pine, and regenerated to hardwoods. Windrow piles are 3 meters wide, 30.5 meters apart, and comprise 10 percent of the tract.

Vegetation and soils were characterized on plots on windrow piles (windrows) and between windrows (inter-rows). Vegetation was measured in 0.0405 hectare rectangular plots on windrows and in two rectangular plots of the same size between windrows. Heights and diameters of pines and diameters of hardwoods were measured. Dominant and co-dominant trees were classified. Site index for loblolly pine was calculated by inputting the dominant and codominant heights into USDA Natural Resource Conservation Service software version (SCS-690) of the site index curves of Schumacher and Coile (1960).

The impact core method was used to sample bulk density. Cores in aluminum cylinders were taken at the surface (0-10 centimeter) and subsurface (10-20 centimeter) depths. Three replicates were sampled at each depth to represent bulk density of a plot. Bulk density was measured for 9 windrow (piled) plots and 9 inter-row plots. All cores were sampled the same day in February, 2000. Cores were weighed in the field-moist state and after oven drying. Pore space and air-filled volume were calculated using these weights.

Soil profiles were described for three windrow locations and ten inter-row locations. Profile locations were located randomly within the tract. Depths, thickness and Munsell colors for the A, E, EB, and BE horizons were measured. Depth to the Bt and thickness of the O horizon was also measured. Texture for each horizon, including the upper Bt, was estimated using the hydrometer method. Each horizon sampled was analyzed by the Louisiana State University Soil Testing Laboratory (Brupbacher and others 1970) for pH (1:1), organic matter (Walkley-Black potassium dichromate oxidation), available phosphorus (Bray 2 ammonium fluoride extraction), and exchangeable (ammonium acetate, pH 7) calcium, magnesium, potassium, and sodium. Phosphorus levels were determined using a spectrometer, and exchangeable cation concentrations were measured using inductively coupled argon plasma emission spectrophotometry (ICP).

Means of windrow position and inter-row soils' horizon thicknesses, physical and chemical properties were compared using the t test procedure in SAS. Equality of variances was tested (F' test), and where the variances were unequal, Satterthwaite's approximate t test was used to test significance (SAS Institute Inc. 1985). Overall significance was determined at the $\alpha = 0.05$ level.

RESULTS AND DISCUSSION

Soil Profiles

Windrow soils had significantly thicker A horizons and deeper depths to the argillic (Bt) horizon (table 1). Transitional horizons such as EB increased depth to the Bt also.

Table 3—Soil chemical properties of A horizons of the windrow (piled) and inter-row position soils

Variable	Windrow Mean	Windrow SE	Inter-Row Mean	Inter-Row SE	Pr>t
pH	5.50	0.21	5.29	0.08	0.2908
Organic Matter, pct	2.23	0.28	2.37	0.30	0.8231
Phosphorus, mg/kg	7.33	0.88	7.30	0.52	0.9756
Calcium, mg/kg	519.00	179.31	338.10	36.36	0.4218
Magnesium, mg/kg	64.00	12.12	64.20	5.39	0.9867
Potassium, mg/kg	31.33	4.67	41.00	3.98	0.2425
Sodium, mg/kg	19.33	0.88	19.80	0.65	0.7245

Table 4—Soil chemical properties of E horizons of the windrow (piled) and inter-row position soils

Variable	Windrow Mean	Windrow SE	Inter-Row Mean	Inter-Row SE	Pr>t
pH	5.30	0.20	5.26	0.10	0.8358
Organic Matter, pct	0.45	0.09	0.64	0.05	0.1085
Phosphorus, mg/kg	4.00	0.58	3.89	0.20	0.8164
Calcium, mg/kg	230.67	62.36	211.00	24.14	0.7226
Magnesium, mg/kg	76.33	8.74	57.67	7.26	0.2045
Potassium, mg/kg	25.33	3.18	23.89	1.05	0.5748
Sodium, mg/kg	18.67	1.20	17.44	0.24	0.4186
Sum of Bases, cmol(+)/kg	1.93	0.38	1.69	0.16	0.5038

Table 5—Soil chemical properties of upper Bt horizons of the windrow (piled) and inter-row position soils

Variable	Windrow Mean	Windrow SE	Inter-Row Mean	Inter-Row SE	Pr>t
pH	4.83	0.03	4.77	0.03	0.2456
Organic Matter, pct	0.48	0.06	0.64	0.04	0.0700
Phosphorus, mg/kg	5.00	0.58	4.80	0.25	0.7217
Calcium, mg/kg	344.33	144.35	260.10	43.77	0.4529
Magnesium, mg/kg	473.67	44.18	389.40	50.81	0.4084
Potassium, mg/kg	129.33	12.00	92.90	5.44	0.0103
Sodium, mg/kg	26.00	2.00	27.40	2.02	0.7279
Sum of Bases, cmol(+)/kg	6.03	0.79	4.84	0.51	0.2742

The O horizon was primarily leaf litter, and did not differ between windrow and inter-row positions. The A, E, and transitional horizons had a sandy loam texture, whereas the Bt horizon was clay or clay loam for all plots.

Physical Properties

Inter-row site soils were significantly denser, had less pore space, and less volume of air than the windrow position soils, both in the surface (0-10 cm) and in the subsurface (10-20 cm) (table 2). Subsurface inter-row soils had a mean bulk density of 1.67 g cm^{-3}. Surface soil removal (7.62 cm) in Alabama Piedmont and Hilly Coastal Plain sites increased bulk density from 1.47 to 1.64 g cm^{-3}, but bulk density decreased to 1.35 g cm^{-3} after three years (Tuttle and others 1985).

Soil Chemistry

There were no significant differences in any of the measured soil chemical properties between windrow and inter-row position A horizon soils (table 3). Calcium content was very variable, particularly on the windrow sites, where one plot had a concentration of 846 mg/kg. There is no evidence of nutrient redistribution. KG bladed surface soils (including Sacul) in southeast Texas had less K, Ca, and Mg than control, chopped, or burned soils (Stransky and others 1985). In that same study, 7 years after harvest and blading, the surface soils had the same amount of organic matter as the chopping treatment. Bladed soils had significantly less Ca, but not significantly less P, K, Mg than chopped or burned soils. Tuttle and others (1985) found that a 7.62 cm surface removal treatment decreased organic matter by over 50 percent with respect to a control, 3 years after removal. In that study, N, P, Ca, Mg, and K were all reduced from control levels three years after surface removal.

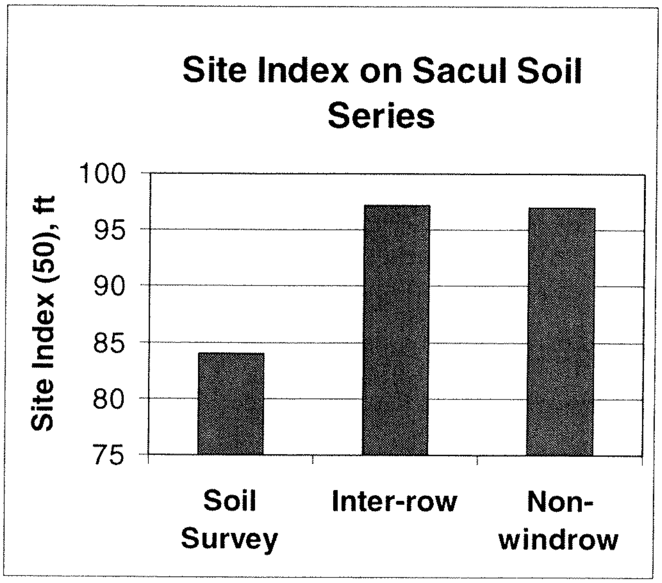


Figure 1—Comparison of loblolly pine site index (base age 50 years) on the Sacul series in Jackson Parish, Louisiana, from Stephens (1999) and measured between windrows and on a non-windrowed area on the study area.

The windrow position E horizons had less (not significant) organic matter than the inter-row sites (table 4). There were no significant differences between site positions for any measured soil chemical property.

The windrow position soils had significantly higher exchangeable potassium levels in the upper Bt, as compared with the inter-row Bt's (table 5). This trend may reflect increased potassium leaching from the slash and through the surface (eluviation), due to increased porosity and infiltration rates in the windrow pile. Potassium could be illuviating in the argillic horizon. Surprisingly, the windrow position Bt horizons contained less organic matter than the inter-row positions had. This trend was also apparent in the overlying E horizons. Prolonged, intense fire in the windrow may have consumed some of the organic matter. Tuttle and others (1983) noted C, Mg, and K appeared to be moving through the upper soil profile 3 years after a surface soil removal.

Overall, there is no evidence in this study for nutrient redistribution from the cleared areas to the piles, or nutrient limitations in the inter-row areas.

Growth of Loblolly Pine

Loblolly pine growing between the windrows had a measured site index of 97.2 feet (figure 1), considerably higher than the published (Soil Survey) figure (using same methods and curve) for the Sacul series in Jackson Parish, LA (Stephens 1999). Loblolly pine on a non-windrowed portion of the tract had a site index of 97.0 feet. The displacement of surface soil and subsequent compaction of the surface and subsurface soil have apparently not severely limited growth of loblolly pine on this site. In contrast to this study, in the Lower Coastal Plain of South Carolina, Fox and others (1989) found that 31 year old loblolly pine between windrows had 10.5 feet lower site index (base age 25 years) as compared with that on non-windrowed sites.

Bulk density in the sandy loam subsurface (10-20 cm) of the inter-row position was 1.67 g cm^{-3} (table 2). Growth limiting bulk density for sandy loam texture is >1.65 g/cm^3 (Daddow and Warrington 1983. Coile and Schumacher (1953) found that 5 cm reduction in surface soil thickness could reduce loblolly pine site index (50 years) by 0.3 to 1.5 m. In the few years following shearing and raking debris into windrows, loblolly pine growth may increase over that of non-windrowed areas. Windrowing, by removing part of the woody competition seed bank and roots, can have a beneficial effect on early pine productivity (Allen and others 1991, Powers and others 1998).

CONCLUSIONS

Twenty-five years after windrowing site preparation, surface and subsurface soils between windrows were significantly compacted, as compared to windrow pile soils. This compaction does not appear to have reduced loblolly pine growth, as compared with growth on an adjacent non-windrowed area . After 25 years, there was little evidence of nutrient redistribution into the windrows. The effectiveness of windrowing in reducing woody competition during early stand development may be a more important factor influencing growth.

REFERENCES

Allen, H.L.; L.A. Morris; T.R. Wentworth. 1991. Productivity comparisons between successive loblolly pine rotations in the North Carolina Piedmont. In: W.J. Dyck; C.A. Mees, ed. Long-term field trials to assess environmental impacts of harvesting. Forest Research Institute New Zealand Bulletin 161, Ministry of Forestry, Forest Research Institute, New Zealand: 125-136.

Brupbacher, R.H.; J.E. Sedberry, Jr.; W.P. Bonner; W.J. Peevy; W.H. Willis. 1970. Fertility levels and lime status of soils in Louisiana. Louisiana Agricultural Experiment Station Bulletin. 644 p.

Coile, T.S.; F.X. Schumacher. 1953. Relation of soil properties to site index of loblolly and shortleaf pines in the Piedmont region of the Carolinas, Georgia, and Alabama. Journal of Forestry. 51: 739-744.

Daddow, R.L.; G.E. Warrington. 1983. Growth-limiting soil bulk densities as influenced by soil texture. WSD6-TN-00005. U.S. Department of Agriculture, Forest Service, Water System Development Group Report.

Foil, R.R.; C.W. Ralston. 1967. The establishment and growth of loblolly pine seedlings on compacted soils. Soil Science Society of America Proceedings.31: 565-568.

Fox, T.R.; L.A. Morris; R.A. Maimone. 1989. The impact of windrowing on the productivity of a rotation age loblolly pine plantation. In: Miller, J.H., comp. Proceedings of the Fifth biennial southern silvicultural research conference; 1988 November 1-3, Memphis, TN. Gen. Tech. Rep. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 133-140

Haines, L.W.; T.E. Mak; S.G. Sanderford. 1975. The effect of mechanical site preparation treatments on soil productivity and tree (Pinus taeda L. and P. elliotti Engelm. var. elliotti) growth. In: Forest soils and land management. Proceedings of the Fourth North American Forest Soils Conference, Laval University, QuJbec. Les Presses de l'UniversitJ Laval, Qubec: 379-395 p.

Haywood, J.D.; J.D. Burton. 1989. Loblolly pine plantation development is influenced by site preparation and soils in the West Gulf Coastal Plain. Southern Journal of Applied Forestry. 13: 17-21.

Morris, L.A.; W.L. Pritchet; B. F. Swindel. 1983. Displacement of nutrients into windrows during site preparation of a flatwood forest. Soil Science Society of America. Journal 47:591-594.

Powers, R.F.; A.E. Tiarks;J.R. Boyle. 1998. Assessing soil quality: practicable standards for sustainable forest productivity in the United States. In : The contribution of soil science to the development of and implementation of criteria and indicators of sustainable forest management. Soil Science Society of America (SSSA) Special Publication Number 53, Madison, WI.

Pye, J.M.; P.M. Vitousek. 1985. Soil and nutrient removals by erosion and windrowing at a southeastern U.S. Piedmont site. Forest Ecology and Management. 11: 145-155.

SAS Institute Inc. 1985. SAS User's Guide: Statistics. Version 5 Edition. SAS Institute, Inc., Cary NC.

Schumacher, F.X.; T.S. Coile. 1960. Growth and yield of natural stands of the southern pines. T.S. Coile, Inc., Durham, NC.

Stephens, W. W. 1999. Soil Survey of Jackson Parish, Louisiana. USDA Natural Resources Conservation Service in cooperation with Louisiana Agricultural Experiment Station and the Louisiana State Soil and Water Conservation Committee.

Stransky, J.J.; J.H. Roese; K.G. Watterston. 1985. Soil properties and pine growth affected by site preparation after clearcutting. Southern Journal of Applied Forestry. 9: 40-43.

Tew, D.T.; L.A. Morris; H.L. Allen; C.G. Wells. 1986. Estimates of nutrient removal, displacement and loss resulting from harvest and site preparation of a *Pinus taeda* plantation in the Piedmont of North Carolina. Forest Ecology and Management. 15: 257-267.

Tuttle, C.L.; M.S. Golden; R.S. Meldahl. 1985. Surface soil removal and herbicide treatment: effects on soil properties and loblolly pine early growth. Soil Science Society of America. Journal 49: 1558-1562.

ASSESSMENT OF DOMINANT/CODOMINANT HEIGHT GROWTH FOR SECOND ROTATION SLASH PINE PLANTATIONS IN SOUTH GEORGIA AND NORTH FLORIDA

Charles E. Rose Jr. and Barry D. Shiver[1]

Abstract—A slash pine (*Pinus elliottii* Engelm.) successive rotation plantation study was established in 1978-79 for the north Florida and south Georgia flatwoods. The second rotation duplicated the first rotation seed source, site preparation, planting method, and density. The comparison between the two rotations is based on the mean height differential for the spectrum and by soil type for each age class. There is a significant rotation 1 minus rotation 2 height difference for all age classes. Rotation 1 is 1.9 and 5.4 ft higher for mean height at ages 2 and 20. Rotation 1 generally experienced more favorable precipitation, for both the amount and timing of the precipitation within a year, than rotation 2. Rotation 2 experienced drought events and high temperatures during the first two growing seasons, while rotation 1 was near normal for this period. The evidence suggests that the main contributor to the decrease in height across the spectrum of plots and age classes is the less favorable overall growing season climatic conditions experienced by rotation 2 relative to rotation 1.

INTRODUCTION

Plantation forestry has an enormous economic impact on the southeastern United States. Maintaining or increasing site productivity is an important economic consideration in the Southeastern United States. There have been conflicting reports with respect to successive rotation productivity during the past several decades (e.g. Thomas 1961, Keeves 1966, Boardman 1978, Haywood 1994, Haywood and Tiarks 1995). Zeide (1992) suggested that there is no reliable evidence that pine growth has declined in the southeast. This issue was addressed by implementing a successive rotation productivity study for slash pine (*Pinus elliottii* Engelm.) plantations in the north Florida and south Georgia flatwoods.

The objectives of this study are to compare the productivity and associated climatic data (precipitation and temperature) for the first and second rotations of these north Florida and south Georgia flatwoods slash pine plantations. The productivity comparison is based on the rotation 1 minus rotation 2 (R1-R2) mean height differential for a range of sites and ages. The height differentials are contrasted by soil types and for the spectrum of soil types for ages 2, 5, 8, 11, 14, 17, and 20. The precipitation comparison is based upon the yearly and monthly total precipitation received by each rotation. The climatic data will also be used to assess any drought events and/or extreme temperature fluctuations by rotation.

DATA

Twenty installations were established on non-old-field plantation slash pine sites in the flatwoods of south Georgia and north Florida during the spring of 1978. Each installation consists of 13 0.5-arce-treatment plots with one plot considered the plantation productivity (previous treatment) plot. The other 12 plots at each installation encompass a slash pine site preparation, fertilization, and vegetation control study, and results from these plots have been reported in several publications, e.g., Shiver et al. (1990), Pienaar and Rheney (1993), Pienaar et al. (1996). Five installations were established in each of the following four soil classes:

- I) poorly drained non-spodosol,
- II) somewhat poorly to moderately drained non-spodosol,
- III) poorly to moderately drained spodosol with an underlying argillic horizon; and
- IV) poorly to moderately drained spodosol with no underlying argillic horizon.

The site indices (base age 25) ranged from 55 to approximately 80. The previous treatment plot at each installation was designed to replicate, as accurately as possible, the characteristics and preparations of the first rotation for a given installation. The previous treatment plot's seed source, site preparation method, planting method and density replicated those of the first rotation at each installation. Currently only 16 of the original 20 installations remain.

The first rotation was harvested in 1978, and site preparation treatments were applied in 1978-79. The previous treatment plots were hand planted using the first rotation spacing design, which varied by location, during the 1979-80 planting season with 1-0 slash pine seedlings.

First Rotation Data Collection

The following information was collected from the plot randomly chosen to be the "previous treatment" plot at each

[1]Graduate Research Assistant, Professor, University of Georgia, Athens, GA, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—The Standardized Precipitation Index (SPI) values and their interpretation (McKee et al. 1993)

SPI value	Interpretation
2.0 and greater	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2.0 and less	Extremely dry

location prior to harvesting the first rotation plots in 1978. All trees within the plot were measured for dbh, total height, crown class, and presence or absence of cronartium (*Cronartium fusiforme*, Hedgc. and Hunt). Additionally, six dominant/co-dominant trees were randomly selected from the previous treatment plot for stem analysis, with disks cut at 6 inches above the ground, 5 feet above ground, and thereafter, at 5 foot intervals.

Second Rotation Data Collection

All trees within the 0.2 acre measurement plots were measured for dbh with the crown class and presence or absence of cronartium recorded. Additionally, one-half of the trees were randomly selected for height measurement with the height being measured on these trees at each measurement period. The second rotation previous treatment plots have been measured on a three-year cycle beginning at age 2 and currently measurements are recorded to age 20.

Climate Data

The climate surface data for a given installation were obtained from the National Climatic Data Center (NCDC 2000). The climate data were obtained from the nearest viable weather station for a given plot. A viable weather station was defined as a station containing the monthly precipitation and temperature information for both rotations. Twelve different weather stations were obtained using this selection method. Most of the viable weather stations were within 5-10 miles of the plots, but some weather stations were approximately 25 miles from the plots. The climatic surface data from these weather stations contain the monthly mean temperature and total monthly precipitation.

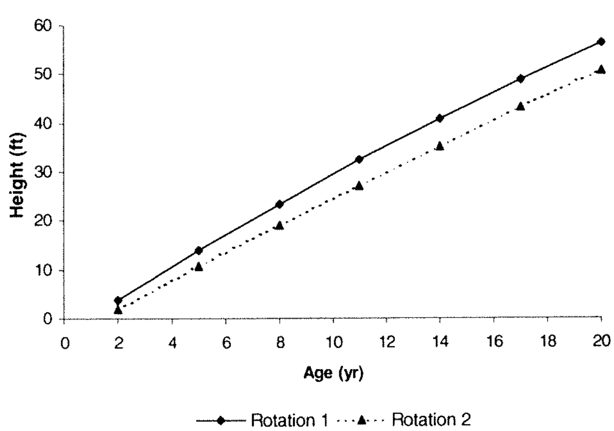


Figure 1—The north Florida and south Georgia slash pine mean

Mean Dominant/Codominant Height Methods

A two-step process was used to assess the height differential between rotations 1 and 2. The first step was to obtain estimates of the mean dominant/codominant heights by rotation and plot for each age class. A mixed model was used to obtain height estimates by rotation and age class for each plot. Secondly, the height point estimates were used to perform an ANOVA by age class. A split-plot model was used to test for rotation height differences. The current data result in an unbalanced split plot model because the replications per soil type are not equal due to the loss of some plots. Soil type was treated as the whole plot and rotation as the split plot. The plots within a soil type were treated as random effects to make inferences across the region. The statistical model used is:

$$H_{ijk} = m + t_i + e_{ij} + b_k + (tb)_{ik} + e_{ijk}.$$

Where H_{ijk} is the mean dominant/codominant height for the j^{th} plot and i^{th} soil type of rotation k,m is the overall mean height,t_i is the i^{th} soil type effect (whole plot),e_{ij} is the whole plot error term (random error on plot j in soil type i),b_k is the rotation effect,$(tb)_{ik}$ is the soil type and rotation interaction effect, and e_{ijk} is the split plot error term (random error for plot j in soil type i and rotation k).

Climatic Data Assessment Methods

An unbalanced split-plot mixed model was used to test for precipitation differences between the rotations. The rotations are treated as the whole plot effect and time is the split-plot effect. The plots within a rotation are treated as random to make region wide inferences. The Standardized Precipitation Index (SPI) and its classification system (table 1) were used to quantify yearly and monthly drought events. McKee et al. (1993) defined a drought event as when the SPI is continuously negative and falls to -1.0 or less. The drought event ends when the SPI becomes positive; therefore the drought event length is defined. The drought magnitude is the sum of the absolute values for all the months or years within a drought period. The average annual and summer temperatures were computed by installation and across the region to assess when or if a rotation experienced extreme temperature fluctuations. The annual and summer temperatures were calculated both as an average for the 16 installations and for each installation individually by rotation.

Dominant/Codominant Height Growth Results

The height estimates for the 16 plots revealed that by age 2, the rotation 1 mean height is substantially higher than rotation 2. The profile plots for both rotations for the spectrum of soil types illustrate that the mean height for rotation 1 is consistently higher than rotation 2 (figure 1). The profile plot exhibits little interaction, which implies that height is an additive effect of rotation and age. The R1-R2 height differential gradually increases across the data range. Profile plots by soil types and soil groups (non-spodosol and spodosol) revealed similar trends.

Table 2—The north Florida and south Georgia first and second rotations slash pine mean dominant/codominant height ANOVA results by age

Source of Variation	NDF*	DDF**	Type III F	Pr > F
Age 2				
Soil	3	12	1.34	0.3083
Rotation	1	12	31.99	0.0001
Soil*Rotation	3	12	1.92	0.1810
Age 5				
Soil	3	12	3.02	0.0719
Rotation	1	12	19.88	0.0008
Soil*Rotation	3	12	0.62	0.6137
Age 8				
Soil	3	12	2.95	0.0757
Rotation	1	12	15.45	0.0020
Soil*Rotation	3	12	0.41	0.7481
Age 11				
Soil	3	12	2.63	0.0982
Rotation	1	12	13.44	0.0032
Soil*Rotation	3	12	0.34	0.7999
Age 14				
Soil	3	12	2.11	0.1517
Rotation	1	12	11.78	0.0050
Soil*Rotation	3	12	0.29	0.8323
Age 17				
Soil	3	12	1.47	0.2724
Rotation	1	12	9.74	0.0089
Soil*Rotation	3	12	0.25	0.8600
Age 20				
Soil	3	12	0.84	0.4983
Rotation	1	12	7.14	0.0204
Soil*Rotation	3	12	0.21	0.8882

* NDF = numerator degrees of freedom.
**DDF = denominator degrees of freedom.

The ANOVA for height by age class revealed that the interaction and main effects tests indicate no significant interaction between soil and rotation (table 2). The soil factor is not significant for all ages (a = 0.05). There is a significant height difference between rotations for all ages, but the significance decreases as age increases. Contrasts for the rotation 1 minus rotation 2 (R1-R2) height differential were constructed and the following is the result synopsis. The contrasts for the R1-R2 pooled height differential are significant for all age classes (a = 0.05). The R1-R2 height differential increases from age 2 to 20, with an average height differential of 5.4 ft by age 20 for the spectrum of plots. The contrasts for the spodosol soil group (soil types III and IV) revealed a significant R1-R2 height differential from ages 2-17, with borderline significance at age 20 (p-value = 0.0518). The spodosols soil group R1-R2 height differential increases to 5.8 ft by age 20. The non-spodosol soil group (soil types I and II) has a significant R1-R2 height differential for ages 2, 5, 8, and 11, and a marginal significant differential for ages 14 and 17 (p-values 0.0532 and 0.0768, respectively). The soil type I contrast revealed no significant R1-R2 height differential for all age classes. Soil type II does have a significant R1-R2 height differential for ages 2, 5, 8, 11, and 14; but the significance decreases so that by age 17, there is only borderline significance (p-value = 0.0693). Soil type III only has a significance R1-R2 height difference at age 2. For soil type IV, there is a significant R1-R2 height difference for the 2-17 age classes and a marginal significance difference at age 20 (p-value = 0.0612). There is an increase in the R1-R2 height differential as a function of age for all soil types except from age 17 to 20 of the soil types II and III.

Table 3—The north Florida and south Georgia first and second rotations slash pine annual precipitation ANOVA results

Source of Variation	NDF*	DDF**	Type III F	Pr > F
Annual Rainfall				
Rotation	1	9.84	2.76	0.1280
Year	19	247	7.61	0.0001
Rotation*Year	19	247	6.91	0.0001

* NDF = numerator degrees of freedom.
**DDF = denominator degrees of freedom.

Climatic Surface Data Results

The ANOVA results for annual precipitation revealed that the interaction between rotation and year is significant (p-value = 0.0001) (table 3). This implies that the amount of annual precipitation for each rotation or year depends upon the level of the other predictor variable. Hence, it is not appropriate to test for rotation main effects across the spectrum of years, but it is appropriate to test for rotation differences by year. The contrasts for testing R1-R2 average annual precipitation differences revealed that rotation 1 received on average, 5.6 and 14.0-inches more precipitation than rotation 2 for the first two years. Rotation 1 had 98 and 104 percent while rotation 2 had 88 and 78 percent of the average precipitation during their first two respective rotation years. Rotation 1 received significantly less rainfall than rotation 2 (8.8 and 9.8-inches) during years 3 and 4, but still had 88 and 97 percent of the average annual precipitation. The years 11 and 12 exhibited the greatest differences with respect to precipitation. Rotation 1 received 19.8 inches more and 11.6 inches less average annual precipitation for these respective years. Rotation 2 received 68 percent of the average annual precipitation for year 11. Although rotation 1 received substantially less precipitation than rotation 2 for year 12, it still received 109 percent of the average annual precipitation.

To compute the SPI index, a square-root transformation was necessary to normalize the precipitation data. The SPI profile plots of the average annual precipitation by rotation reveal that rotation 2 exhibits more variability relative to rotation 1 for the yearly SPI index (figure 2). Rotation 1 experienced one minor drought event (years 3-4) for annual precipitation during the 20 years. Rotation 2 has experienced two previous drought events (years 1-2, and 10-11), and is currently in the third year (1998-2000) of a drought event. Since the height growth decrease for rotation 2 loss relative to rotation 1 was expressed by age 2, the SPI precipitation by month was computed for the initial two years of each rotation (figure 2). The average monthly SPI revealed that rotation 1 did not experience a growing season drought event during the first two growing seasons. Rotation 2 experienced growing season drought events during both of the first two growing seasons.

The temperature data revealed that rotation 2 had below average annual temperatures during the first two years, but during the same period, it had substantially above normal

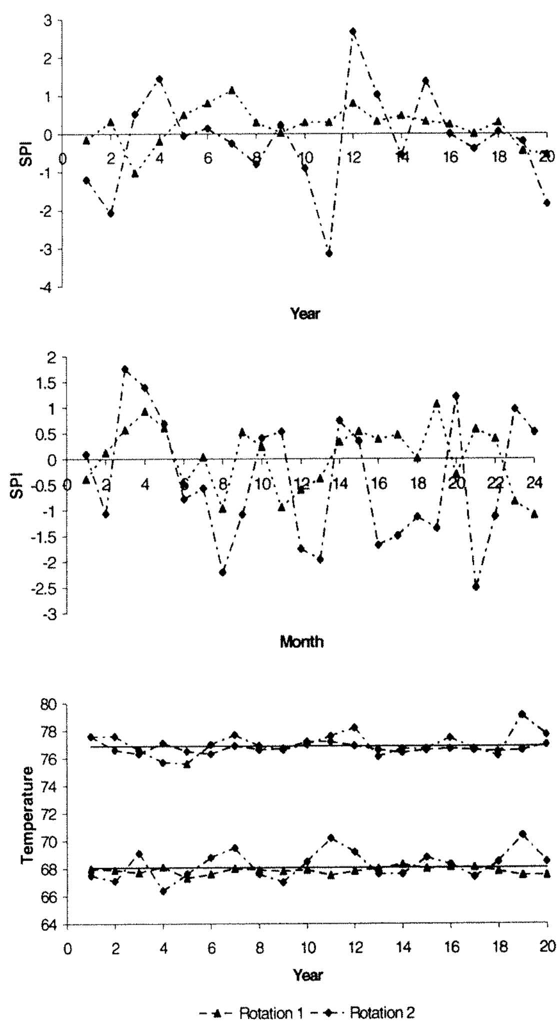


Figure 2—The north Florida and south Georgia slash pine standardized precipitation index (SPI) for mean annual precipitation by year and for the first 24 months (month 1 corresponds to January of the first year). The mean annual and growing season (higher) temperatures by rotation and year. The 69-year weighted average for the growing season and annual temperatures are represented by the solid lines.

temperatures for the growing season (figure 2). Rotation 2 average growing season temperature for the first 2 years was 77.6° F, which is substantially above the average growing season temperature of 76.9° F.

DISCUSSION

The results from the ANOVA for the spectrum of plots by age class revealed a significant height difference between the rotations. Rotation 1 is, on average, 1.9, 3.2, 4.2, 5.0, 5.4, 5.6, and 5.4 feet higher for height than rotation 2 at ages 2, 5, 8, 11, 14, 17, and 20, respectively. The height significance decreases as age increases; but an average R1-R2 height loss of 5.4 feet at age 20 is considerable. The contrasts by soil types don't insinuate any general trend between soil type and the R1-R2 height differential.

It is difficult to quantify competing vegetation or nutrient availability for either rotation because of the lack of data for these factors. The main competitors at most plots for both rotations are gallberry (*Ilex glabra*) and saw palmetto (*Serenoa repens*). There is no indication that the quantity of gallberry and/or saw palmetto has dramatically changed from rotation 1 to rotation 2. The climate data analyses suggest that drought events and warmer growing season temperatures generally correspond with smaller height growth, especially during the first two years. The data revealed that the decrease in height growth experienced by rotation 2 was expressed by age 2. This age 2 height differential corresponds with less favorable growing conditions, on average, experienced by rotation 2 during the first two growing seasons.

The plantation productivity plots used for this study are a separate entity of the study on slash pine site preparation, fertilization, and vegetation control. The goals of the larger study are to evaluate the growth, yield, and stand structure of slash pine plantations using different combinations of site preparation, fertilization, and vegetation control. The site preparation methods used for the productivity study plots were, on average, similar to a chop and burn site preparation. The heights for rotations 1 and 2 were compared with the chop and burn treatment heights. The genetic stock of the first and second rotation productivity plots are different, likely inferior, to the site preparation study plots. The chop and burn plots average heights are 2.7 and 48.8 feet at ages 2 and 20, respectively. The first and second rotation productivity plots mean heights for ages 2 and 20 are 3.4 and 57.1 feet, and 2.1 and 47.0 feet, respectively. This implies that the early rotation climatic conditions have a more profound effect on height growth than genetic stock, for these chop and burn plots.

It is generally accepted that extreme weather temperatures, marginal precipitation, competition, and nutrient deficiency can adversely affect seedling growth. The second rotation, on average, exhibits a height reduction, but the first rotation harvest disturbance is not likely a mitigating factor because management impact was minimized to insure the second rotation duplicated the first rotation as accurately as possible. The main competition for both rotations is gallberry and saw palmetto, but not necessarily at the same densities, therefore competition is not likely the main factor for the mean dominant/codominant height growth loss experienced by rotation 2. Since the genetic stock was the same for both rotations, genetics is not likely the major factor for the height differential between rotations 1 and 2. Because no information is available, a nutrient deficiency can't be eliminated, although it is unlikely, as a major contributor to the R1-R2 height differential. The evidence suggests that the more severe drought events and warmer temperatures experienced by rotation 2, especially during the first two growing seasons, is the main factor for the rotation 2 reduction in height for the spectrum of plots and age classes.

REFERENCES

Boardman, R. 1978. Productivity under successive rotations of radiata pine. Australian Forestry. 41: 177-179.

Haywood, J.D. 1994. Early growth reductions in short rotation loblolly and slash pine in central Louisiana. Southern Journal of Applied Forestry. 18(1): 35-39.

Haywood, J.D.; A.E. Tiarks. 1995. Growth reductions in short-rotation loblolly and slash pines in central Louisiana—10th year results. In: Proceedings of the eight biennial southern silvicultural research conference, Edwards. M.B., ed; 1994 November 1-3; Auburn AL. Gen. Tech. Rep. SRS-1. Asheville NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 268-274.

Keeves, A. 1966. Some evidence of loss of productivity with successive rotations of *Pinus radiata* in the southeast of South Australia. Australian Forestry. 30: 51-63.

McKee, T. B.; N. J. Doesken; J. Kleist, 1993. The relationship of drought frequency and duration to time scales. In: Preprints, 8th Conference on Applied Climatology; 1993 January 17-22; Anaheim, CA: 179-184.

NCDC: National Climatic Data Center. 2000. U.S. Department of Commerce, National Oceanographic and Atmospheric Administration. <http://nndc.noaa.gov/?home.shtml>.

Pienaar, L.V.; J.W. Rheney. 1993. The effect of different site preparation treatments on slash pine plantation growth in the Atlantic coastal plain. In: Brissette, J.C. ed., Proceedings of the Seventh Biennial Southern Silvicultural Research Conference; 1992 November 17-19; Mobile AL. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 431-436.

Pienaar, L.V.; B.D. Shiver; J.W. Rheney. 1996. Yield prediction for mechanically site-prepared slash pine plantations in the southeastern coastal plain. Univ. of Georgia Plantation Manage. Res. Coop. Res. Pap. 1996-3. 57 p.

Shiver, B.D.; J.W. Rheney; M.J. Oppenheimer. 1990. Site-preparation method and early culutural treatments affect growth of flatwoods slash pine plantations. Southern Journal of Applied Forestry. 14(4): 183-188.

Thomas, J. 1961. Two rotations of *Pinus radiata*. Institute of Foresters of Australia, Newsletter Vol. 2 13: 4-5.

Zeide, B. 1992. Has pine growth declined in the Southeastern United States? Conservation Biology. 6: 185-195.

OAK PLANTINGS AND NATURAL INVASION OF TREE SPECIES ONTO FORMER AGRICULTURAL FIELDS IN THE LOWER MISSISSIPPI RIVER VALLEY

Bobby D. Keeland, Brian Roy Lockhart, John W. McCoy, and Thomas J. Dean[1]

POSTER SUMMARY

Greater than 80 percent of the bottomland hardwood forests of the Lower Mississippi Alluvial Valley (LMAV) have been lost to conversion over the past 100 years. Of the forests that remain, most are highly fragmented and degraded. Attempts to reforest some of this area over the past 15-20 years have highlighted the need for more information on the relative success of various planting techniques. Controversies still clouds the merits of direct seeding versus planting bare rootstock, and information on broadcast seeding is also lacking. Very little information exists on natural invasion dynamics that are often expected to provide additional tree species and increase diversity. To test a variety of planting methods, the U.S. Fish and Wildlife Service, Louisiana Department of Wildlife and Fisheries, and the Louisiana State University initiated a study during the fall of 1993. Researchers from the Louisiana State University and the U.S. Geological Survey sampled the plots six years later, during the fall of 1999. This poster presented an overall summary of the study. Two additional papers on the study are included in these proceedings and several other manuscripts are planned for future publication (see below).

At each of four locations (Lake Ophelia National Wildlife Refuge [NWR], Tensas River NWR, Bayou Macon Wildlife Management Area [WMA], and Ouachita WMA) 14 treatment combinations were established in a randomized complete block design on 0.4 ha (1-acre) permanent study plots. Treatments consisted of 6 combinations of direct seeding using no till, single disking, double disking, strip disking, and rolling (table 1). Planting was accomplished by using a maximerge planter or a cyclone broadcast planter. Each treatment was further replicated with a fall (1993) and spring (1994) planting. In addition bareroot seedlings were planted by hand and machine during the winter (January/ February 1994).

Three oak species were used in the study (table 2); Nuttall oak (*Quercus texana*), water oak (*Q. nigra*), and willow oak (*Q. phellos*). Each treatment was replicated 3 times for each oak species for a total of 84 plots each at Tensas River NWR and Bayou Macon WMA where two species of oaks were planted, and 42 plots each at Lake Ophelia NWR and Ouachita WMA where only one species of oak was planted.

After the 6th growing season (fall 1999) 4 subplots (100 m^2 each, 20 m in toward the center of the main plot from each corner) were sampled in each plot to determine the number and heights of planted oaks and any woody invaders. All tree seedlings/saplings greater than 30 cm tall were identified and categorized by height class (30-50 cm tall, 51-100 cm tall, 101-140 cm tall, greater than 140 cm tall, and greater than 2.5 cm DBH).

Overall, 16,511 seedlings and saplings (greater than 30 cm tall) were recorded in this study. This number included 7,022 planted oaks for an average of 697 oaks and 941 woody invaders per ha. Oak survival was mixed with respect to species and location. Nuttall oak survival was

Table 1—Planting treatments and season of planting

Treatment	Season
Double Disk, Maximerge Direct Seed	Fall, Spring
Double Disk, Maximerge Direct Seed, Roll	Fall, Spring
Strip Disk, Maximerge Direct Seed	Fall, Spring
No-Till, Maximerge Direct Seed	Fall, Spring
Single Disk, Cyclone Broadcast Seed, Single Disk	Fall, Spring
Single Disk, Cyclone Broadcast Seed, Single Disk, Roll	Fall, Spring
Hand Plant Bare Root Seedlings	Winter
Machine Plant Bare Root Seedlings	Winter

[1]Research Ecologist, USGS, National Wetlands Research Center, Lafayette, LA 70506; Associate Professor, School of Forestry, Wildlife & Fisheries, Louisiana State University, Baton Rouge, LA 70803; General Biologist, USGS, National Wetlands Research Center; Associate Professor, School of Forestry, Wildlife & Fisheries, Louisiana State University, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 2—Oak species planted at each refuge/wildlife management area

Species	Tensas River NWR	Lake Ophelia NWR	Ouachita WMA	Bayou Macon WMA
Nuttall Oak	X	X		X
Willow Oak			X	X
Water Oak	X			

higher at Bayou Macon WMA and Tensas River NWR compared to Lake Ophelia NWR, while willow oak survival was much better at Ouachita WMA compared with Bayou Macon WMA.

Species composition of the invaders varied significantly by site, probably being affected by the species composition of the adjacent forests. The highest densities were at Bayou Macon where more than 1,200 stems/hectare were recorded. Both Bayou Macon WMA and Tensas River NWR were dominated by 3-4 species (sugarberry, ash and elms) with lesser amounts of several other species. The lowest densities were found at Lake Ophelia NWR, where a broad mixture of species and no overall dominant was found, and at Ouachita WMA where one species, saltbush, dominated.

Planting treatments had significant effects on natural invasion by woody species. Greater numbers of invaders were found on the no-till and strip disk treatments than on treatments that were more thoroughly disked. This effect, however, was caused by the combined responses of the ashes, sugarberry and elms. Invasion rates of most other species were not affected by disking.

OTHER RELATED MANUSCRIPTS PRESENTED AT THE 11TH ANNUAL BSSRC

Michalek, Alexander J., Brian Roy Lockhart, Thomas J. Dean, Bobby D. Keeland and John W. McCoy. 2001. Comparison of hand planting versus machine planting of bottomland red oaks in former agricultural fields in Louisiana's Mississippi Alluvial Plain: Sixth-year results.

McCoy, John W., Bobby D. Keeland, Brian Roy Lockhart, and Thomas J. Dean. 2001. Pre-planting site treatments and natural invasion of tree species onto former agricultural fields at Tensas River National Wildlife Refuge, Louisiana.

ANTICIPATED FUTURE MANUSCRIPTS

Broadcast Seeding in Bottomland Hardwood Reforestation
Spring versus Fall Planting of Red Oaks in the Lower Mississippi Alluvial Valley
Comparison of Planting Bare-Root Seedlings versus Direct Seeding of Bottomland Red Oaks.
No-till, Strip Disking and Double Disking: A Comparison of Effects on Natural Invasion and Red Oak Survival.

Site Preparation and Classification

Moderator:

JOHN TOLBERT
Mead Corporation

FOREST CLEARCUTTING AND SITE PREPARATION ON A SALINE SOIL IN EAST TEXAS: IMPACTS ON WATER QUALITY

Matthew McBroom, Mingteh Chang, and Alexander K. Sayok[1]

Abstract—Three 0.02 hectare plot-watersheds were installed on a saline soil in the Davy Crockett National Forest near Apple Springs, Texas. Each plot was installed with an H-flume, FW-1 automatic water level recorder, Coshocton N-1 runoff sampler, and two storage tanks. One watershed was undisturbed forested and served a control, one was clearcut without any site-preparation, and the third was clearcut, V-blade sheared, windrowed, and vegetation regrowth was prevented for the first 2 years. A total of 274 storms were recorded during the four-year study period, 1989-1992. Average annual sediment losses for the study period were 55, 197, and 1,530 kilograms per hectare per year for the control, commercial clearcut, and sheared plots, respectively. These losses are about average for most studies conducted in East Texas and the Southeast and are well below average losses for all land uses in the Southeast. Sediment losses and surface runoff were significantly greater from the sheared plot-watershed than from the control and the commercial clearcut plots. Employing Wischmeier and Smith's (1978) long-term average R-value for the USLE overestimated annual sediment yield for the study period, while two shortcut models developed in the United States resulted in more accurate predictions and are good substitutes for the long-term R-value. Total losses in surface runoff of PO_4, NO_3, NO_2, TKN, K, Ca, Mg, Na, Al, Fe, Zn, and Cu were higher on the site-prepared plot watershed than the other two. Losses of PO_4, TKN, and NO_2 were higher on the commercial clearcut plot than the control. Losses were not high enough to adversely affect forest productivity. Concentrations of elements were generally below established USEPA surface water quality standards and were not high enough to adversely affect plant growth.

INTRODUCTION

Commercial clearcutting is the most common silvicultural system employed for the regeneration of upland forests in East Texas. Following harvest, sites are usually prepared for planting by mechanical techniques such as shearing, chopping, bedding, ripping or some combination of these activities. Concern has arisen regarding possible degradation of site productivity over time and possible degradation of water quality (USEPA 1993).

There are more than 120,000 hectares of somewhat poorly drained, upland saline soils in central East Texas (between Sam Rayburn Reservoir and Livingston Reservoir). These soils have high salt concentrations, low permeability, and are frequently saturated. Upland vegetation is predominately mixed pine/hardwood, with loblolly (*Pinus taeda*) and shortleaf (*Pinus echinata*) pine dominating the overstory. Conversion of these natural stands to plantations can be difficult, reporting as many as three attempts with no success in some areas. J-rooting and limited lateral root development at about 15 centimeters below the surface is frequently observed on theses sites. High mortality rates are thought to be the result of a rise in the water table following harvest, seedlings experiencing salt toxicities, nutrient imbalances, or some combination of these factors. Surface runoff from clearcut sites on these soils could negatively impact water quality as well.

This study was initiated in 1988 to examine the impacts of clearcutting and site preparation on sediment movement and water quality from a saline soil in East Texas. The results from the first two years were presented in Sayok and others (1993a and 1993b) on sediment and element movements and Chang and others (1992) on applications of the universal soil loss equation. Effects on soil properties were reported in Chang and others (1994). This report summarizes the results of all four years of data collection.

METHODS AND PROCEDURES

Study Area

This study was conducted during the water years 1989 through 1992 in the Davy Crockett National Forest near Apple Springs, Texas, about 200 kilometers north of Houston and 250 kilometers southeast of Dallas. The area is characterized by a humid subtropical climate with prevailing winds from a southerly direction. Precipitation is fairly evenly distributed throughout the year. Winter precipitation is associated with frontal activity while summer precipitation is dominated by convective storms of high intensity, low frequency and short duration. Precipitation during the study period was 1,119 millimeters, 1,236 millimeters, 1,295 millimeters, and 1,208 millimeters for the 1989, 1990, 1991, and 1992 water years (October-September), respectively. These amounts were much

[1]Doctoral Graduate Assisteant and Professor of Forest Hydrology, Arthur Temple College of Forestry, Stephen F. Austin State University, Nacogdoches, TX 75962; KTA Consulting Engineers, Box 1312, 93726 Kuching Sarawak, Malysia, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Annual rainfall, surface runoff, and sediment losses for three forested conditions near Apple Springs, Texas for water years 1989-1992[a]

	Water Year				
Parameters	1989	1990	1991	1992	Average
Rainfall (Pt mm)	1,119	1,236	1,295	1,208	1,215
Number of Storms	63	55	77	79	69
Surface Runoff (Ro mm)					
Forested	14 A	68 A	31 A	9 A	31 A
Clearcut	60 B	107 B	59 A	38 A	66 B
Sheared	299 C	577 C	404 B	375 B	414 C
Runoff/Rainfall (Ro/Pt percent)					
Forested	1.2	5.5	2.4	0.8	2.5
Clearcut	5.4	8.6	4.5	3.1	5.4
Sheared	26.7	46.7	31.2	31.0	34.1
Sediment Loss (kg ha^{-1})					
Forested	56 A	72 A	33 AB	61 B	55 A
Clearcut	422 B	287 B	50 B	33 A	198 B
Sheared	2,374 C	2,916 C	725 A	116 B	1,533 C

[a] Different letters in a given year indicate that the means of all events are significantly different at $\alpha \leq 0.05$

higher than the normal (1951-1980) annual precipitation of 1,077 millimeters observed at the Lufkin Airport about 22 kilometers east of the study site.

The area is characterized by gently rolling topography with slopes averaging 2 to 10 percent. Severe erosion can occur on slopes above 2 percent. The soil of the study site is Fuller fine sandy loam, a member of the fine loamy siliceous, thermic family of Albic Glossic Natraqualfs. The salinity of these soils results from volcanic ash blown from the Cook Mountain Formation during the Eocene epoch and deposited on siltstones or mudstones. The area was inundated by ocean water and the volcanic ash was compacted. Silty materials were blown from the west and settled on the compacted ash.

Loblolly and shortleaf pines dominated the overstory with a mixture of post oak (*Quercus stellata*), red oak (*Quercus falcata*), white oak (*Quercus alba*), sweetgum (*Liquidambar styraciflua*), and hickories (*Carya* spp.). Merchantable

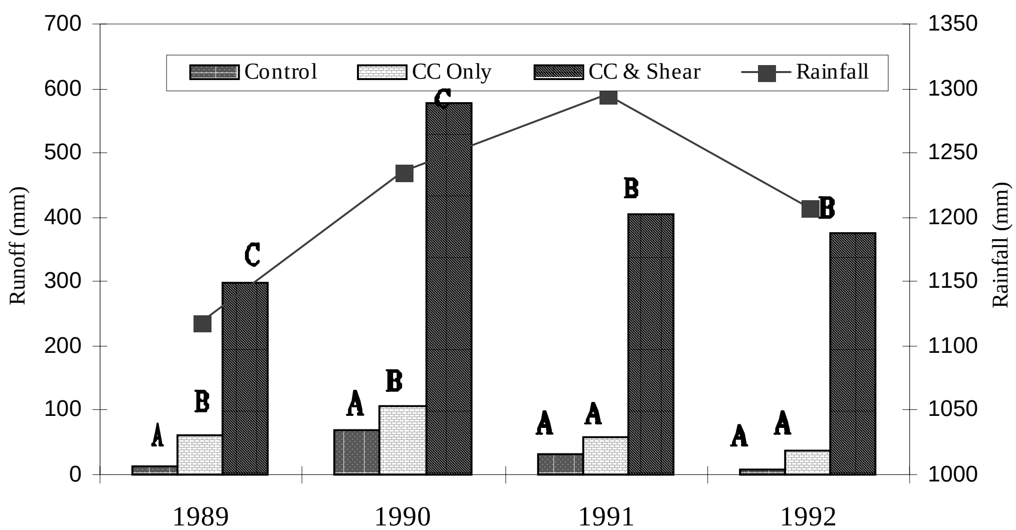


Figure 1—Surface runoff and rainfall by treatment and water year for Apple Springs, Texas

trees ranged from 30 to 55 years of age in 1988 with an average height of 28.5 meters, diameter at breast height of 25 centimeters, site index (50) of 27 meters, and basal area of 21.81 square meters per hectare.

Treatments

Three treatments were employed in this study: 1) undisturbed forest with full crown closure as a control, 2) commercial clearcut with all merchantable timber removed, other vegetation and logging debris left intact, and 3) commercial clearcut with all vegetation removed, stumps sheared with V-blade D6 crawler tractor, and all debris windrowed. Vegetation was prevented from regrowing by hand shearing with no soil disturbance for the first two years following treatment. To avoid potential edge effects, the distance from the sides of the plots to the surrounding stand was at least 30 meters. Harvesting was conducted on July 23-24, 1988 and site preparation on August 26, 1988. Due to budget constraints, treatments were not replicated.

Plot Watersheds and Data Analysis

Each plot was 0.02 hectares in size (9.14 meters by 22.13 meters) and was located in each treatment area to monitor surface runoff and soil and element losses generated by storm events. All plots were located within a 3.24 hectare area, with comparable environmental conditions regarding vegetation, soils, slope, and aspect. A plywood barrier 8 centimeters below and 7 centimeters above the ground bordered each plot. At the lower end of each plot an approach apron, a 15.4 centimeter H-flume, a stilling well with an FW-1 water level recorder, a Coshocton N-1 runoff sampler, and a storage tank were sequentially connected together. The Coshocton wheel diverted about 1 percent of the surface runoff into a small storage tank. The small tank was confined in a larger tank designed to accommodate surface runoff generated by 48-hour 50-year storms. Total soil loss from each storm runoff event was the sum of sediment deposited in the apron and approach section plus suspended sediment collected in the storage tank. Volumes of surface runoff were directly measured from the storage tank and also interpreted from the charts of the water-level recorders.

The volume of surface runoff generated from each runoff event was converted to depth. Samples were collected after each runoff event and were transported to the Stephen F. Austin State University Arthur Temple College of Forestry Forest Hydrology Laboratory for chemical analyses of 19 water quality parameters. Methods and procedures for water quality analyses were reported in Sayok (1991) and Sayok and others (1993b).

USEPA's (1986) water quality standards were used as a reference to evaluate surface runoff water quality conditions. Data failed to meet the assumption of normality for parametric statistical analyses. Therefore, the nonparametric Kruskall-Wallis test as described by Hollander and Wolfe (1999) and SAS Institute, Inc (1999) was employed to determine differences in concentrations among the three treatments. The Wilcoxon's rank sum procedure was used to evaluate multiple comparisons where the Kruskall-Wallis test found differences to be significant at $a \leq 0.05$.

The data were also stratified into summer- (May – October) and winter- (November – April) half years for testing seasonal effects on surface water quality. Seasonal differences were determined using the Wilcoxon's rank sum procedure.

RESULTS AND DISCUSSION

Rainfall and Runoff

Rainfall during the four year study period was considerably higher than the average rainfall (1951-1980) of 1,077 millimeters reported at the Lufkin Airport about 22 kilometers east of the study area (table 1). Highest precipitation occurred in water year 1991 with 218 millimeters or 20 percent more precipitation than normal.

Annual surface runoff generated from the plots varied considerably with treatment and by water year (table 1). Since all vegetation, stumps, and debris were removed and no regrowth of vegetation was allowed for the first two years, the sheared plot had the least transpiration and interception loss among the three plots. Furthermore, the soil was compacted by the heavy machinery, resulting in a decrease in infiltration rate and an increase in soil moisture content. Bulk densities were found to be greater following treatment (Chang and others 1994). This translated to more total surface runoff from the sheared plot and greater runoff efficiency. Average runoff as a percent of rainfall (Ro/Pt) for the four-year period was 34 on the sheared plot and only 3 and 5 on the control and commercial clearcut plots, respectively. The percent Ro/Pt ratio for the clearcut plot (5) was about the same as reported by two other East Texas studies: 6 in Cherokee County (Blackburn and others 1986) and 8 in Nacogdoches County (Chang and others 1982). However, percent Ro/Pt ratio for the sheared plot was higher (34) than values reported in Nacogdoches (29) and Cherokee (11) counties. Runoff as a percent of precipitation did not decline significantly on the sheared plot during the study period. Ro/Pt was 31 percent during year four, whereas it was 27 percent during year one. This may be due to the lower permeability and higher soil moisture content of the saline soil.

Using the Kruskall-Wallis test and Wilcoxon's rank sum, the sheared plot were found to be significantly different from the control at $a \leq 0.05$ for all four years (figure 1). During water years 1989 and 1990, all three plots were significantly different from one another. However, during water years 1991 and 1992, the commercial clearcut plot was not significantly different from the control plot (figure 1).

Sediment Losses

Annual Losses—Sediment losses were highly significant among treatments. First year sediment losses were 56, 422, 2,347 kilograms per hectare for the control, cleared, and sheared plots, respectively (table 1). Losses among plots were significantly different the second year following treatment as well. This difference is due to greater soil disturbance on the shear treatment, resulting in more exposed bare soil. By the third year, the control and cleared plots were no longer significantly different, although the losses of sediment on the sheared plot remained

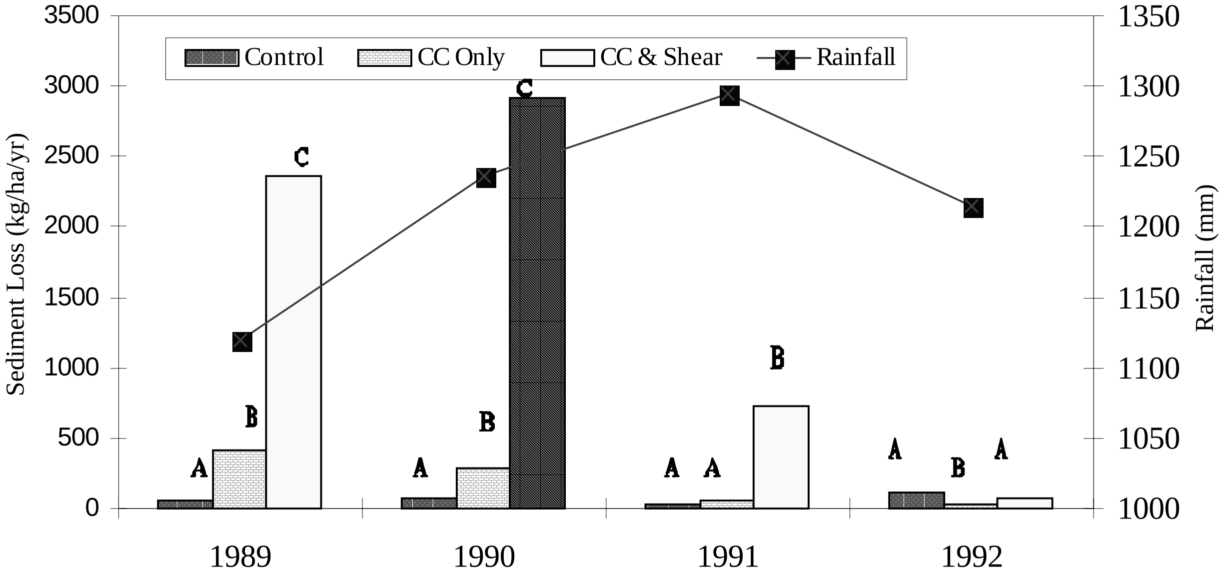


Figure 2—Sediment loss and rainfall by treatment and water year for Apple Springs, Texas.

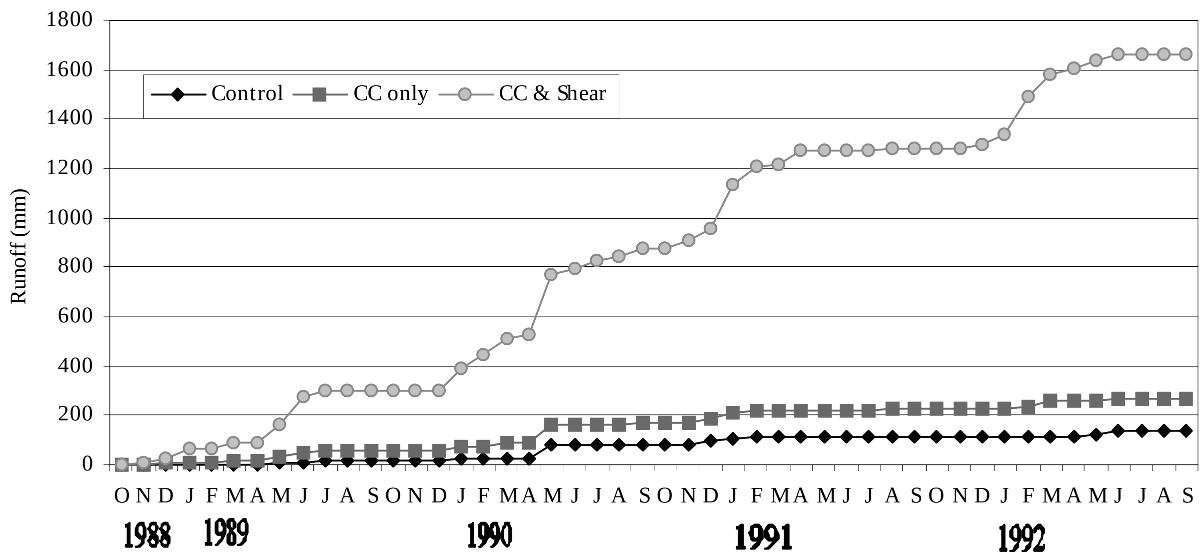


Figure 3—Cumulative runoff for three forest treatments at Apple Springs, Texas.

significantly different. By the fourth year, the sheared and control plots were no longer significantly different. Overall, the sheared plot generated about 28 times more sediment than the commercial clearcut plot and 8 times more than the forested plot. About 44, 70, 79, and 54 percent of the total annual sediment loss was produced from the five largest storms for water years 1989, 1990, 1991, and 1992, respectively.

Soil losses decreased over time on the two treatment plots throughout the study period. On the commercial clearcut plot, this was due to rapid vegetative regrowth following harvest, an indication that vegetation is an effective medium in controlling erosion and sediment transport, despite a 10 percent increase in rainfall from the first year to the second. On the sheared plot vegetative regrowth was prevented for the first two years, and sediment losses remained high during this time (figure 2). During the second year following harvest, the 10 percent increase in rainfall might account for the increase in total sediment loss. Vegetation was allowed to regrow during years three and four, and sediment losses declined until by year four in which sediment losses were no longer significantly different from the control plot. Sediment losses were slightly higher on the control plot during the second year. This could be due to the increase in rainfall. Also, a tornado occurred on January 19, 1990 that resulted in about a 50 percent opening in the canopy. Following the tornado, three large storms occurred that resulted increased sediment yield from the control plot. Greater sediment losses were associated with late winter and early spring when rainfall and runoff rates were greatest (figures 3 and 4).

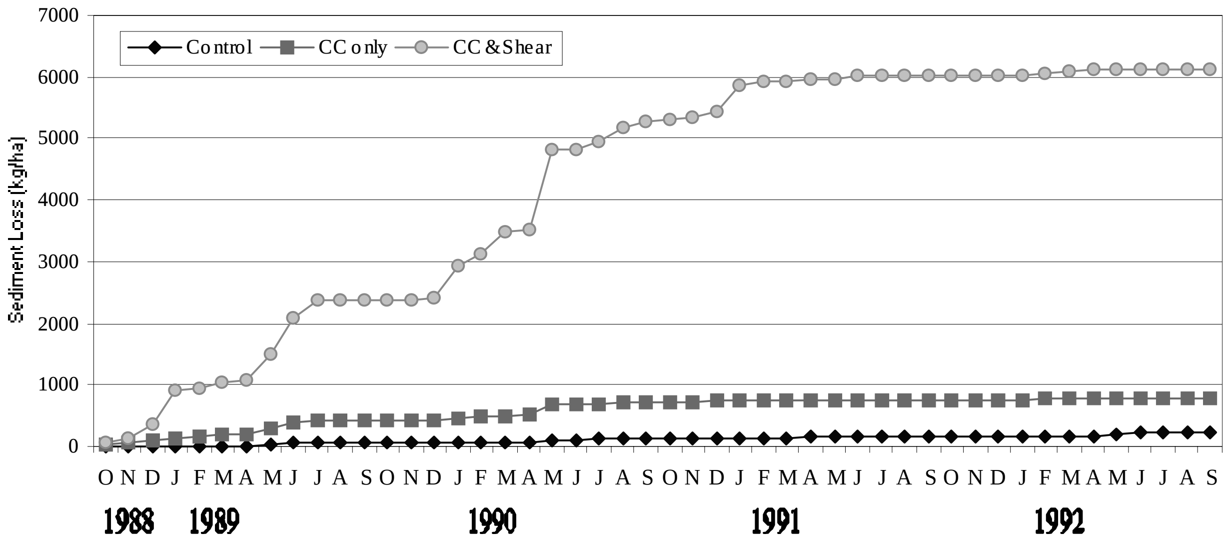


Figure 4—Cumulative sediment loss for three forest treatmnts at Apple Springs, Texas.

Comparison to Other Studies

Based on 16 other studies throughout the southeast USA, Yoho (1980) reported that sediment losses ranged from 2 to 717 kilograms per hectare per year for undisturbed forested watersheds. Sediment losses from the control plot are within the lower end of this range. First year sediment loss for the sheared plot was also within the range of losses reported for other studies in East Texas, 3,462 kilograms per hectare near Etoile, (Chang and others 1982), 2,937 kilograms per hectare near Alto (Blackburn and others 1986), and 306 kilograms per hectare in San Augustine County (Blackburn and others 1990). In this study, first year losses observed from the sheared plot were below those observed near Etoile and Alto, but greater that those observed in San Augustine County.

Several studies have also reported that about 3-4 years are required for sediment losses from sheared plots to return to observed levels on undisturbed areas in the southeast (Blackburn and others 1986; Blackburn and others 1990; Miller 1984). In this study, losses were no longer significant by year four. This period could have been shorter had vegetation regrowth not been prevented during the first two years of the study.

Sediment Estimates

The Universal Soil Loss Equation (USLE) was employed to estimate average sediment losses for the study plots during the study period. The equation estimates sediment A = RKLSCP in which the six factors are related to rainfall, soil, slope length, slope steepness, vegetation/management, and conservation practices, respectively. The C-factor employed was based on values observed for East Texas forests (Chang and others 1982) as they were found to be the most accurate estimates for the East Texas environment (Chang and others 1992). However, the C-value for the sheared plot during the last two years was obtained from Wischmeier and Smith (1978) to account for vegetation regrowth. Thus the long-term C-value for the sheared plot was estimated by averaging the C-values from these two sources. Values of KLSP were based on the standard procedure given by Wischmeier and Smith (1978). R-values were obtained by using the standard Wischmeier and Smith (1978) procedure along with eight other shortcut models developed in various regions (table 2). The standard EI_{30} (kinetic energy x 30 minute intensity) method for calculating R-values requires rainfall intensity information for all runoff-producing storms. This information may not be available and calculations are tedious. If the shortcut methods, generally using annual rainfall to correlate with EI_{30} values, can provide satisfactory estimates, then the use of USLE would be greatly facilitated for stations with only total rainfall.

Estimating sediment losses using R-values obtained from Wischmeier and Smith's (1978) long-term average (US Agricultural Handbook No 537) resulted in about a 143 and a 118 percent overestimation of sediment losses for the shear and commercial clearcut plots, respectively (table 3). However, the two shortcut models developed in the United States (Models 4 and 9) provided sediment estimates for these two plots within 23 percent of those from the observed values. Also, reasonable estimates for these two sites could be obtained from the two models developed in the two tropical regions (Models 3 and 5) with errors less than 50 percent. All estimates by these four models of sediment losses for the forested plot resulted in greater percent errors than for the treatment plots. Because of the relatively small magnitudes of losses from forested areas, these errors are of less concern.

Element Losses

Concentrations of elements were generally below USEPA surface water quality standards and not significantly

Table 2—Ten different models for calculating R-values (metric ton m/ha/hr per yr) for the USLE

Model	Location	Reference
1 $R = [\Sigma^N \Sigma^M(EI_{30})]/(100N) *1.735$	United States	Wischmeier and Smith (1978)
2 $R = 0.5 (P)*1.735$	West Africa	Roose (1975)
3 $R = (9.28(P)-8838 \times I30)*0.001$	Malaysia	Morgan (1974)
4 $R = 0.276 P \times I30 \times 0.01$	United States	Foster and others (1981)
5 $R = (38.46+3.48P) \times 0.1$	Hawaii	Lo and others (1985)
6 $R = (0.264*((\sum_{i=1}^{12} p_i^2)/P)^{1.50})$	Morocco	Arnoldus (1977)
7 $R = (0.04830P^{1.610})*0.1$	United States	Renard and Freimund (1994)
8 $R = (587.8-1.219P+0.004105P^2)*0.1$	United States	Renard and Freimund (1994)
9 $R = (0.07397*((\sum_{i=1}^{12} p_i^2)/P)^{1.847})*0.1$	United States	Renard and Freimund (1994)

Note: E = storm kinetic energy (metric ton-m ha^{-1} cm^{-1}), I_{30} = maximum 30 minute storm intensity (cm hr^{-1}), I30 = maximum annual maximum 30 minute rainfall intensity (assumed to be 75 mm hr^{-1}), P = mean annual rainfall (1989-1992) in mm, p_i = mean monthly rainfall (1989-1992), N = number of years, and M = number of storms in each year.

Table 3—Observed and estimated average sediment losses (kg/ha/yr) by the USLE with R-values obtained by nine different models in Apple Springs, Texas

	Forest		Clearcut		Shear	
Source	Loss	Diff[a]	Loss	Diff[a]	Loss	Diff[a]
Observed	55	0	198	0	1,533	0
Estimated						
Model 1	37	-33	431	118	3,729	143
Model 2	54	-1	639	223	5,520	260
Model 3	10	-83	113	-43	976	-36
Model 4	13	-76	152	-23	1,316	-14
Model 5	22	-59	264	33	2,278	49
Model 6	68	23	799	303	6,903	351
Model 7	23	-57	276	39	2,385	56
Model 8	27	-51	319	61	2,760	180
Model 9	14	-75	160	19	1,381	-10

[a]Percent difference where diff = ((obs-est)/obs)*100

Table 4—Mean concentrations (mg/L) and mass losses (g/ha) for 17 elements in the study area for water years 1989-1992[a]

	Mass Losses[b]			Concentrations[b]		
Parameter	Control	Clearcut	Shear	Control	Clearcut	Shear
PO_3	28.46 A	35.76 B	194.52 C	2.92 A	3.44 A	2.61 A
NO_3	3.11 A	4.44 A	42.77 B	0.31 A	0.29 A	0.29 A
NO_2	1.32 A	6.95 AB	10.18 B	0.09 A	1.52 A	0.19 A
NH_4	38.41 A	76.77 B	264.48 C	3.16 A	3.25 A	2.53 A
TKN	99.90 A	123.50 B	448.60 C	5.71 A	5.13 A	4.26 A
K	45.41 A	85.64 A	347.38 B	5.73 A	6.74 A	7.55 A
Cl	208.20 A	253.10 A	1331.80 B	15.57 A	15.42 A	15.34 A
Na	124.40 A	204.51 A	730.12 B	21.07 A	16.92 A	10.91 A
Ca	36.25 A	55.98 A	212.86 B	3.43 A	3.72 A	3.12 A
Mg	44.20 A	43.93 A	168.78 B	2.17 A	2.42 A	2.49 A
Al	4.35 A	6.03 A	49.98 B	0.25 A	0.45 A	1.20 A
Mn	7.20 A	7.74 A	18.92 A	0.01 A	0.26 A	0.27 A
Fe	8.30 A	15.39 A	53.90 B	0.37 A	0.61 A	0.49 A
Zn	23.37 A	42.59 A	105.31 B	0.62 A	1.38 A	1.61 A
Cu	2.19 A	4.25 A	30.45 B	0.28 A	0.27 A	0.36 A
SO_4	188.00 A	243.20 A	993.70 A	26.05 A	20.65 B	12.90 B
HCO_3	325.00 A	543.00 A	957.60 B	45.29 A	55.43 B	38.08 A

[a] Nutrient parameters (PO_4, NO_3, NO_2, NH_4, and TKN) were only measured during water years 1989 and 1990.
[b] Mean values with different letters in a given year are significantly different at $\alpha \leq 0.05$.

different between treatments (table 4). This is due to the dilution effect of greater runoff volume from the treatment plots. However, when concentrations are converted to mass per unit area, elements were found to be different between treatments. Mass losses in grams per hectare were greater from the sheared plot than from the commercial clearcut or the control (table 4). Losses of sodium (Na), chloride (Cl), Calcium (Ca), magnesium (Mg), and aluminum (Al) were especially high. Elements were generally not significantly different between the control and the clearcut plot. However, nutrient parameters such as ortho-phosphorus ($PO_{4)}$, ammonia ($NH_{4)}$, and total Kjeldahl nitrogen (TKN) were significantly greater on the commercial clearcut plot than the control plot.

A comparison of element losses by water year illustrates a general attenuation trend with time. Losses of elements such as Na, Cl, Ca, Mg, and Al were greater from the sheared plot than the control in water year 1989 and 1990. After regrowth of vegetation, only Na and Cl losses remained higher on the sheared plot. Sodium losses following shearing in other East Texas studies were 343 grams per hectare (Blackburn and others 1986) and 380 grams per hectare (Muda and others 1989), much lower than losses observed in this study, 730 grams per hectare. Higher rates of export of Na and Cl would be expected from a saline soil. Vegetative regrowth resulted in reduced rates of Ca and Mg export.

CONCLUSION

Harvesting and mechanical site-preparation greatly reduced evapotranspiration, disturbed soil structure, and increased soil moisture content, resulting in greater runoff volumes and losses of sediment, nutrients, and elements. However, erosion problems did not seem to be serious enough to adversely affect land productivity. Following regrowth of vegetation, losses decreased dramatically until by the fourth year following treatment no differences were observed between the treatments and the control. Neither treatment plot was reforested by artificial means, yet after two years of vegetation regrowth, runoff volumes and sediment losses were no longer different from the undisturbed forest plot. Wischmeier and Smith's (1978) long-term average R-value for the USLE overestimated annual sediment yield for the study period. Two shortcut models developed in the United States for estimating the rainfall factor resulted in more accurate predictions and are good substitutes for the EI_{30} factor in the study area.

REFERENCES

Arnoldus, H.M.J. 1977. Methodology used to determine the maximum potential average soil loss due to sheet and rill erosion in Morocco. FAO Soils Bulletin. 34: 39-51.

Blackburn, W.H; R.W. Knight; J.C. Wood; H.A. Pearson. 1990. Stormflow and sediment loss from intensively managed forest watersheds in East Texas. Water Resource Bulletin. 26: 465-477.

Blackburn, W.H; J.C. Wood; M.G. DeHaven. 1986. Storm flow and sediment losses from site-prepared forestland in East Texas. Water Resource Research. 22: 776-784.

Chang, M; F.A. Roth, II; E.V. Hunt, Jr. 1982. Sediment production under various forest site conditions. In: D.E. Walling, ed. Recent Developments in the Explanation and Prediction of Erosion and Sediment Yield. Proc. Of the Exeter Sym.; 1982 July; IAHS Publ. 213. Paris, France: 13-22.

Chang, M.; A.K. Sayok; K.G. Watterston. 1992. Comparison of three proposed C-values of the soil loss equation for various forested conditions. In: The Environment is Our Future. Proc. of the 23rd Annual Conference of the International Erosion Control Association; 1992 February; Reno, NV: 241-246.

Chang, M; A.K. Sayok; K.G. Watterston. 1994. Clearcutting and shearing on a saline soil in East Texas: impacts on soil physical properties. In: Edwards, M.B., comp. Proceedings of the Eighth biennial southern silvicultural research conference; 1994 November 1-3, Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 209-214.

Foster, G.R.; L.J. Lane. 1981. Simulation of erosion and sediment yield from field-sized areas. In: Lal, R.; E.W. Russel, eds. Tropical Agricultural Hydrology. Wiley, NY: 375-394.

Hollander, M.; D.A. Wolfe. 1999. Nonparametric Statistical Methods, 2d ed. New York, NY: John Wiley & Sons, Inc.

Lo, A; S.A. El-Swaify; E.W. Dangler; L. Shinshiro. 1985. Effectiveness of EI30 as an erosivity index in Hawaii. In: S.A. El-Swaify; W.C. Moldenhauer; A. Lo, eds. Soil Erosion and Conservation. Soil Conservation Society of America, Ankeny, IA: 384-392.

Miller, E.L. 1984. Sediment Yield and storm flow response to clearcut harvest and site preparation in the Ouachita Mountains. Water Resource Research. 20: 471-475.

Morgan, R.P.C. 1974. Estimating regional variations in soil erosion hazard in Peninsular Malaysia. Malaysia National Journal. 28.

Muda, A.B.; M. Chang; K.G. Watterston. 1989. Effects of six forest-site conditions on nutrient losses in East Texas. p. 55-64. In: Woessner W. W. and D. F. Potts (eds). Headwaters Hydrology. Proc. Of the American Water Resources Association, June, 1989, AWRA Pub. Num. TPS-89-1, Missoula, MT.

Renard, K.G.; J.R. Freimund. 1994. Using monthly precipitation data to estimate the R-factor in the revised USLE. Journal of Hydrology. 157: 287-306.

Roose, E.J. 1975. Erosion et ruissellement en Afrique de l'aouse: cingt annees de measures en petites parcellec experimentales, Cyclo. ORSTON, Adiopodoume, Ivory Coast. In: Morgan, R.P.C. 1979. Soil Erosion and Conservation. Longman Publishers: Essex, England.

SAS Institute. 1999. SAS/STAT Users Guide, Version 8. SAS Institute, Inc. Cary, N.C.

Sayok, A.K.; M. Chang; K.G. Watterston. 1993a. Forest clearcutting and site preparation on a saline soil in East Texas: impact on sediment losses. p. 177-183. In: R.H. Hadley, ed. Sediment Problems: Strategies for Monitoring, Prediction and Control. The Sixth Intern'l Sci. Assembly, IAHS, Yokohama, Japan July 11-23. IAHS Publ. 217.

Sayok, A.K.; M. Chang; K.G. Watterston. 1993b. Forest clearcutting and site preparation on a saline soil in East Texas: impact of element movement. p. 125-133. In: R.H. Hadley, ed. Sediment Problems: Strategies for Monitoring, Prediction and Control; 1993 July 11-23; The Sixth Intern'l Sci. Assembly, IAHS, Yokohama, Japan IAHS Publ. 217.

United States Environmental Protection Agency. 1986. Quality Criteria for Water. Washington, DC.

United States Environmental Protection Agency. 1993. Water Quality Effects and Nonpoint Source Control Practices for Forestry: an Annotated Bibliography. EPA 841-R-97-008.

Wischmeier, W.H; D.D. Smith. 1978. Predicting rainfall erosion losses. Agr. Handbook #537. Washington, D.C: U.S. Department of Agriculture. 58 p.

Yoho, N.S. 1980. Forest management and sediment production in the South – a review. Southern Journal of Applied Forestry 4:27-36.

THE BOTTOMLAND HARDWOODS OF THE HATCHIE RIVER, THE ONLY UNCHANNELIZED MISSISSIPPI TRIBUTARY

Roger Steed, Jennifer Plyler, and Edward Buckner[1]

Abstract—Documenting the natural condition of the floodplain forests of Mississippi River tributaries becomes ever more elusive as cultural alterations continue to obscure their "original" character. The 4,532 hectare Hatchie National Wildlife Refuge (HNWR) in West Tennessee provides the best-available opportunity to document the floodplain forests that once flourished along the major tributaries of the Mississippi Embayment. Of five major Mississippi tributaries in Tennessee, the Hatchie is the only one that remains unchannelized. Characterizing these "original" floodplain forests was the purpose of this study.

Forest cover types were classified according to species and soil-site relationships. Since these poorly drained soils do not have distinct pedogenic horizons, the single determinant used for distinguishing soil types was depth to gleying (DTG). Six DTG classes were used to delineate soil drainage/tree species relationships. The tree species comprising the forest cover types were classified as "indicator" or "plastic" based on their apparent affinity for specific ranges in DTG. Indicator species were restricted to specific topographic and soil conditions while the plastic species were found on a wide variety of topographic and soil conditions.

INTRODUCTION

Of the five major Mississippi tributaries in West Tennessee all except the Hatchie have been channelized to prevent flooding and/or enable farming. Where successful, this process destroyed the original wetland condition. This major alteration of the bottomland hydrology over much of the Mississippi Embayment has caused serious disruption of both wildlife habitat and forest productivity. Current management options being considered include returning the channelized tributaries to their original channels.

Although the Hatchie continues to follow essentially its natural course, the composition and structure of floodplain forests have been altered by agricultural clearing, siltation, and "high grading" that has removed commercially valuable trees leaving trees of lesser value to restock the area. Only on the Hatchie National wildlife Refuge (HNWR) (established in 1962) are there remnant examples of the character of the "original," pre-historic forests. Historically, these sites supported high quality forests that were widely distributed over the Mississippi and tributary river bottomlands. However, sedimentation, land clearing, and channelization have greatly reduced both the acreage in, and stature of, this resource (Turner and others, 1981). The composition and character of the original forest communities that once dominated these floodplains were largely controlled by the ability of component species to tolerate various degrees and periods of inundation and soil saturation. The first bottoms usually had standing water during part of the year followed by varying degrees and depths of soil drainage.

Since the early 1800's, changing land uses in the alluvial valleys of the Mississippi Embayment has resulted in a rapid decrease in bottomland hardwood forest cover types (Sternitzke, 1975 and 1976). As early as 1818, these fertile bottomlands were cleared for cotton production. By 1825 the region had developed into an important cotton producing area. Most of the well drained sites adjacent to the river were being cleared while the frequently flooded bottoms remain in forest (Sternitzke, 1955).

Again in the 1960's large areas of bottomland forests were cleared for agricultural crops, especially soybeans. This high-return crop was well-suited to these productive sites. Sedimentation, channelization, and beaver impoundments have further deminished both the acreage and quality of the bottomland forest resource (Sternitzke, 1955 and Wells and others, 1974). Between 1950 and 1971, the acreage in bottomland hardwoods decreased by one-fourth in the southeast.

Sedimentation from the eroding uplands continues to degrade the bottomland hardwood resource. The soils of West Tennessee are primarily derived from loess, and are highly erodible. Poor agricultural practices were noted as early as 1860 and continued for more than a century. Sedimentation has caused increased flooding due to impaired drainage through deposition in the floodplains and channels (U.S.D.A., 1977). However, in the last decade there has been a significant improvement in the soil-loss problem in West Tennessee, largely through no-till agricultural practices (from 14.1 tons per acre per year in 1977 to

[1]USDA Forest Service, Coconino National Forest, Happy Jack, AZ 86024 Ph.D; USDA Forest Service P.O. Box 96090 Washington, DC 20090-6090; Professor Emeritus Department Forestry, Wildlife & Fisheries, University of Tennessee P.O. Box 1061 Knoxville, TN 37901-1061, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

7.1 tons per acre per year in 1992 according to the National Resource Inventory). Channelization, levees (both natural and artificial), and siltation have created a habitat that is well suited for beavers, whose impoundments have caused high mortality in some of the last remaining bottomland forests (Byford, 1974).

Trends in conversion to agronomic crops have changed over the past decade primarily due to abandonment of agricultural lands. Although bottomland forest acreage is now increasing (Tennessee Agricultural Statistics, 1980-1982, and 1987-1991), their composition and character has been greatly altered.

According to current definitions, much of the original bottomland hardwood acreage could have been classified as "wetland." Wetlands have recently been recognized as among our most valuable and important ecosystems. Wetlands are transition zones typically found between open waters and land resources. These "in-between places" provide a setting for the dynamic interactions that occur where terrestrial and aquatic systems meet, which make wetlands ecologically valuable (Jensen, 1988). The continuing loss of these diverse transition zones is a major ecological concern.

OBJECTIVES

The objectives of this study were:

(1) to characterize the "natural" bottomland hardwoodre source on a section of a major Mississippi tributary in West Tennessee that remains relatively undisturbed,

and

(2) to determine the relationships between soil-site properties and forest cover types of the Hatchie water shed.

THE STUDY AREA

The Hatchie River is a drainage system for southwestern Tennessee. Its headwaters drain north-central Mississippi before entering Tennessee along the Hardeman-McNairy county line. It flows in a northwest direction through Hardemen and Haywood counties, finally forming the border between Tipton and Lauderdale counties before entering the Mississippi River approximately 56 miles north of Memphis.

The bottomland soils are Entisols (Soil Survey Staff, 1975). Due to their recent development, they do not have distinct pedogenic horizons (Buol and others, 1973). Depth to redoximorphic features such as redox concentrations, redox depletions and reduced matrix (gleying) were the soil properties used to distinguish between different soils in these broad floodplains. The alternating bands of grey/brown or "gley horizons" are indicative of anaerobic conditions caused by saturation most of the year. This prevents the oxidation reactions that impart the reddish color characteristic of most better drained soils.

The Hatchie National Wildlife Refuge (HNWR) is located near Brownsville, Tennessee. It extends approximately 40 km in an east-west direction along the Hatchie River floodplain. This area contains remnants of the only "natural" forests to be found on a major Mississippi tributary in Tennessee. Although siltation from poor farming practices on adjacent uplands has modified site conditions, these forests approximate the "original" or "natural" condition of tributary floodplain vegetation.

STUDY METHODS

Only sites considered to be relatively "undisturbed" were selected for characterizing "natural" forest conditions. Prior to land acquisition for the HNWR, approximately one-half of the forest land had been disturbed by fire, grazing, and/or timber cutting. Only 1,214 ha or approximately one-third of the total Refuge acreage was considered suitable for this study.

Compartment maps of the Refuge (scale of 1/24,000) were used to locate suitable study areas. Sample points were located every 100 m along lines 800 m apart; the first line was randomly located. Any portion of a transect within 400 m of a major disturbance, such as powerlines, highways, or drainage canals, was eliminated. Small adjustments were made to keep the vegetation tallied at each sample location completely within a topographic drainage class. A total of 127 plots was established along 12 transects.

Soils and vegetation were sampled at each sample location. Topographic position and evidence of abnormal flooding were noted. Depth to, and degree of development of reduced matrix (gleization) were used to distinguish different soils. Soil samples were collected from the 0 to 30 cm, 30 to 60 cm, and 60 to 120 cm depths for laboratory analysis to determine pH, K and P levels. Depth to gleying (DTG) was determined using a soil auger.

Arborescent vegetation was sampled using a 2.5 m^2/ha prism. Crown position, diameter breast height (DBH- at 1.3 m ground), and total height were estimated for each "count" tree. DBH and total height estimates were periodically checked using a diameter tape and an Abney level, respectively. Each tree was assigned to a crown class as follows; dominant, codominant, intermediate, and overtopped (Smith, 1962). Dead trees were noted with comments on the gap size their death created. Abundance and height were determined for understory trees and shrubs (between 1 and 4 m in height).

The arborescent vegetation of the study area was characterized for each of six DTG classes. DTG Class 1 represented the poorest drainage condition with mottling apparent in the surface soil. As class number increased mottling was progressively deeper and surface horizons were better aerated. These DTG classes and the soil series they represent were:

Class	Depth-to-gleying	Mapped as
1	Surface gleying	Waverly
2	> 0 but < 15 cm	Waverly
3	15 to 30 cm	Falaya
4	30 to 45 cm	Falaya or Collins
5	45 to 60 cm	Collins
6	60 to 120 cm	Collins or Vicksburg

Characteristics of the four major soil series present were (Brown and others, 1973, 1978; Flowers, 1964):

1) Waverly series - poorly drained soils in the lowest part of the floodplain (coarse-silty, mixed, acid, thermic Typic Fluvaquents).
2) Falaya series - better drained soils on flats and ridges (coarse-silty, mixed, acid, thermic Aeric Fluvaquents).
3) Collins series - moderately well-drained soils on narrow ridges that follow stream channels (coarse-silty,mixed, acid, thermic Aquic Udifluvents).
4) Vicksburg series - well-drained soils on the highest ridges (coarse-silty, mixed, acid thermic Typic Udifluvents).

Soil pH, K and P were analyzed on 273 soil samples from 91 plots by the University of Tennessee Agricultural Extension Service Soil Testing Lab in Nashville. Correlation coefficients and their corresponding probabilities were calculated using SAS (1985). Only coefficients significant at p = 0.05 and lower were used in soil/site - forest cover correlations.

RESULTS AND DISCUSSION

Field sampling revealed little evidence of pedogenic horizon development in soils that underlie the wide, nearly level floodplain of the Hatchie River. These Entisols developed in alluvium and are characterized by an ochric epipedon.

Of the 127 plots sampled, 39 were on soils of the Waverly series, 58 were on Falaya soils, 26 were on Collins and 4 were on Vicksburg. The well drained sites were on natural levees immediately adjacent to the Hatchie River while poorly drained sites were in sloughs and swamps away from the river (generally in old river channels and ox-bow lakes) (figure 1).

Forest cover types were segregated along a soil aeration gradient which was reflected by DTG. Overstory trees and woody understory vegetation were characterized for each DTG class. Figure 1 summarizes the relationship between topographic position, DTG, and overstory trees. Some

Overstory	A.Beech* Yellow poplar* White oak* Sweetgum Swamp Chestnut Oak Cherrybark Oak	Sweetgum Cherrybark Oak* Willow Oak Swamp chestnut Oak Water Oak Silver Maple Swamp Hickory Shagbark Hickory*	Sweetgum Willow Oak Overcup oak Swamp Hickory Baldcypress Silver Maple Chestnut Oak	Overcup oak* Baldcypress* Willow Oak	Sweetgum Willow oak Cherrybark Oak Swamp Chestnut Oak Overcup oak* Swamp Hickory Water Oak Pin Oak	Sweetgum Cherrybark Oak Swamp chestnut Oak Willow Oak Shagbark Hickory* Water Oak Swamp Hickory Mockernut Hickory*	Tupelo gum* Baldcypress Overcup Oak	Sweetgum Swamp Chestnut Oak Water Oak Shagbark Hickory* Cherrybark Oak Shumard Oak Mockernut Hickory* Yellowpoplar A.Beech	Sweetgum CherryBark Oak Swamp Chestnut Shagbark Hicory* Water Oak Mockernut Hickory* Blackgum*
Understory	A.Holly Pawpaw Estern Hophorn-beam Stiff Dogwood Cane	A.Elm A.Hornbeam Sweetgum Deciduous Holly Swamp Chestnut Oak	Planer Tree A.Elm A. Hornbeam Sweetgum Deciduous Holly	Paner Tree Deciduous Holly	Planer tree A. Hornbeam A.Elm Sweetgum Deciduous Holly	A.Elm A.Hornbean Grapevine Greenbriar Sweetgum Swamp Chestnut Oak Shagbark Hickory*	Buttonbursh Planer Tree Virginia Willow	A. Hornbeam Sweetgum Grapevine Greenbriar Shagbark Hickory* Swamp Che-stnut Oak Pawpaw	A.Hornbeam A.Elm Swamp Chestnut Oak Sweetgum Shagbark Hickory* Cane

*Indicator Species

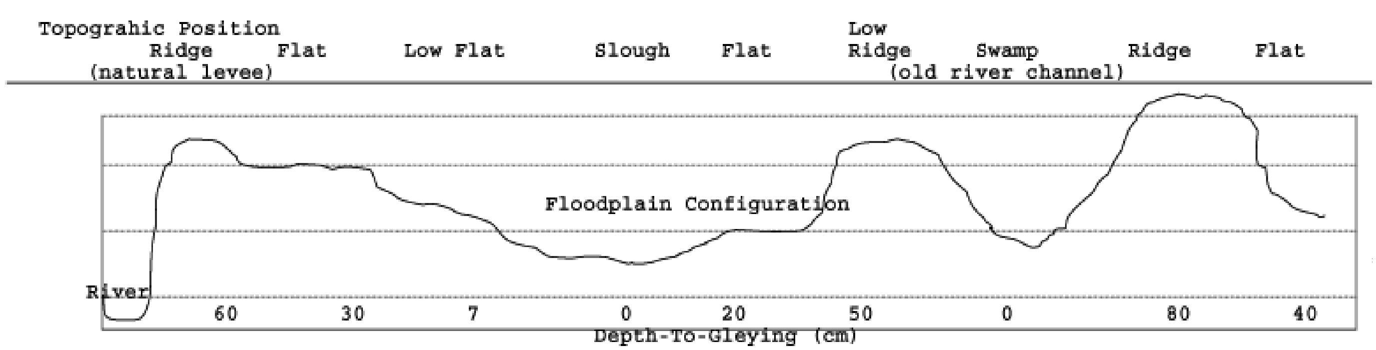


Figure 1—Overstory and understory species and topographic position in the Hatchie Wildlife Refuge.

species were found only on specific DTG classes while others were very plastic, occurring on all or most DTG classes. The site-specific trees are good indicators of soil drainage and, in turn, soil series. Indicator species and their associate DTG classes and soil series are:

TUPELO gum DTG = 0 cm (Surface gleying) Soil Series = Waverly

The presence of tupelo gum (*Nyssa aquatica* L.) was indicative of swamp areas where gleying occurred at the ground surface (DTG 0 cm). While surface water may disappear in areas supporting tupelo gum during the midsummer and fall, surface soil moisture remains at or near saturation throughout most of the growing season. These soils are commonly called "mucks."

BALDCYPRESS DTG = 0-20 cm: Soil Series = Waverly

As soil aeration improved, tupelo gum was replaced by bald-cypress (*Taxodium distichum* (L.) Rich). This intolerant conifer is unique in that it is maintained in and along ox-bow lakes and is favored by frequent flooding which suppresses its more shade- tolerant competition. In bald-cypress groves, DTG was commonly from just below the surface to 20 cm. This "deciduous evergreen" grew best on "mucks" but occurred on a wide range of soil draniage conditions. In the absence of frequent flooding, baldcypress was replaced by overcup oak (*Quercus lyrata* Walt.).

OVERCUP oak DTG = 0-20 cm: Soil Series = Waverly

While overcup oak was relatively plastic in its occurrence (DTG 0 to 20 cm), it was most common on areas where flooding was annual but not continuous. Along with tupelo gum and baldcypress, overcup oak was one of the most flood-tolerant species. It was common in sloughs and swamps. However, it grew better on low-lying clays or silty clay flats in first bottoms and the terraces of larger streams.

TERRACE hickories DTG = 20-50 cm: Soil Series = Falaya & Collins

The terrace hickories, shagbark (*Carya ovata* (Mill.) K. Koch) and mockernut (*Carya tomentosa* (Poir.) Nutt.), marked a transition from low flats (DTM = 7 cm) to flats and low ridges (DTG = 20-50 cm). Shagbark hickory was the predominant species, adapting successfully to a variety of soil conditions. Mockernut hickory, a common associate of shagbark, was found on somewhat better-drained sites than those favoring shagbark. Soil conditions favorable to mockernut hickory ranged from deep, fertile surface horizons to poorly drained loams with a fragipan. Both shagbark and mockernut hickory were common on dry sites and ridges where swamp chestnut oak (*Quercus michauxii* Nutt.) and water oak (*Quercus nigra* L.) were the predominant species.

Where shagbark and mockernut hickory were a significant component of the overstory, understory vegetation included seedlings of shagbark hickory and American elm (*Ulmus americana*, L.) and swamp chestnut oak saplings.

BLACKGUMDTG = 40 cm: Soil Series = Falaya & Collins

Blackgum (*Nyssa sylvatica* Marsh.) was not a dominant species in any of the forest associations identified but did reflect specific drainage conditions. It was consistently found on flats where DTG was 40 cm or greater. It grew best on well-drained, light textured soils on low ridges of second bottoms or on high flats of silty alluvium. On upland sites loams and clay loams produced the best growth. Where blackgum was common in the overstory, American elm and American hornbeam (*Carpinus caroliniana* Walt.) were frequent understory components.

AMERICAN BEECH - yellow-poplar - white oak DTG = 60-80 cm: Soil Series = Vicksburg

The most consistent indicator species for the better-drained soils were American beech (*Fagus grandifolia*, Ehrh), yellow-poplar (*Liriodendron tulipfera* L.), and white oak (*Quercus alba* L.). These hardwoods marked a shift from flat, wet sites to high well-drained ridges. Yellow-poplar and white oak were especially indicative of improved soil drainage. Soils were usually alluvial, deep, fertile, moist, and highly productive.

Common understory associates included planer tree (*Planer aquatica* (Walt.) J.F. Gmel.) and American hornbeam which were replaced on drier sites by a dense understory of stiff dogwood (*Cornus foemina* Mill.), pawpaw (*Asimina triloba* (L.) Dunal), eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch), and American holly (*Ilex opaca* Ait. f. *opaca*).

Although these high ridges contained the more valuable commercial species, the average stand basal area progressively decreased as depth to gleying increased. This was due in part to competing vegetation other than trees; approximately 50 percent of these sites had extensive encroachment from vines.

A comparison of the forest types found on first bottoms of the HNWR with the Society of American Foresters (SAF) Forest Cover Types for the Southern Forest Region revealed that the following were represented: 1) baldcypress (101), 2) baldcypress-tupelo (52), and yellow-poplar-white oak-northern red oak (102) (Eyre, 1980).

The terrace hickories presented a unique situation. Although they do not comprise a designated SAF forest cover type, their silvical characteristics suggest that their occurrence in river bottoms is not unusual. According to Burns and Honokala (1990), shagbark and mockernut hickory grow best in humid climates and tolerate a wide range in soil-site conditions. Common associates of the terrace hickories include indicator species such as tupelo gum, yellow-poplar, blackgum, white oak, and American beech plus a number of bottomland hardwood species.

CONCLUSION

This study revealed well-defined relationships among native tree species, soil series, topography, and soil drainage classes in the first bottom of the Hatchie River. These include:

1) The most poorly drained sites were the "mucks" found in swamps and sloughs. Topographically these were generally the lowest points with gleying at the ground surface - soils were of the Waverly series. Indicator species included baldcypress and tupelo gum. Similar associations were found in ox-bow lakes.
2) Low flats, flats, and low ridges provided better-drained sites. Depth to gleying varied from 20 to 50 cm indicating better drainage of the surface horizons. These better drained soils belonged to the Falaya series. Common indicator species included the terrace hickories and blackgum.
3) The natural levee immediately adjacent to the river provided the best drained site in the first bottom. It was generally the highest feature in the first bottom and had a high sand content that encouraged rapid drainage. These well-drained soils belonged to the Vicksburg series. Indicator species were American beech, yellow-poplar, and white oak. Similar associations were found on former levees along abandoned stream channels and oxbow lakes.

These forest cover - soil drainage relationships provide insight as to the likely character of the "original" floodplain forests that once bordered the mid-continent section of North America's largest river and its major tributaries.

REFERENCES

Brown, W.T.; W.C. Jackson; C.L. Keathley; C.L. Moore. 1973. Soil survey: Obion county, Tennessee. U.S.D.A., S.C.S., Series 1962. U.S. Government Printing Office, Washington, D.C.

Brown, W.T.; G.L. Keathley; C.T. Conner. 1978. Soil survey Madison county, Tennessee. U.S.D.A., S.C.S, Series 1973. U.S. Government Printing Office, Washington, D.C.

Buol, S.W.; F.D. Hole; R.J. McCracken. 1973. Soil genesis and classification. Iowa State University Press, Ames. 360 p.

Burns; Honokala. 1990. Silvics of North America, Vol. 2. Hardwoods. U.S.D.A. Forest Service. Agricultural Handbook 654. Washington, DC.

Byford, J.L. 1974. Beavers in Tennessee: control, utilization, and management. The University of Tennessee Agricultural Extension Service Publication 687. 15 p.

Eyre, F.H. editor. 1980. Forest cover types of the United States and Canada. Society of American Foresters. Washington, DC.

Flowers, R.L. 1964. Soil survey: Fayette county, Tennessee. U.S.D.A., S.C.S., Series 1960. U.S. Government Printing Office, Washington, D.C. 71 p.

Jensen, Lawrence J. 1988. Wetlands mitigation: an EPA view of opportunities and problems. *In* Proc. Wetlands Increasing Our Wetlands Resources; 1987. Washington, D.C. :National Wildlife Federation. 24-28.

SAS Institute, Inc., 1985. SAS Procedures: Guide for personal computers (Version 6 edition), Cary, NC:SAS Institute, Inc., 373 p.

Smith, D.M. 1962. The practice of silviculture. John Wiley & Son, Inc., New York. 578 p.

Soil Conservation Service. 1975. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. U.S.D.A. Agricultural Handbook No. 436. 754 p.

Sternitzke, H.S. 1955. Tennessee's timber economy. U.S.D.A. Forest Resource Report No. 9. 56 p.

Sternitzke, H.S. 1975. Shifting hardwood trends in the South.

Sternitzke, H.S. 1976. Impact of changing land use on Delta hardwood forests. Journal of Forestry. 74:25-27 p.

Tennessee Agricultural Statistics. 1979-82. U.S.D.A. Agricultural Statistics Board Publication Nos. T-16 thru 19. Nashville, Tennessee.

Tennessee Agricultural Statistics. 1987 thru 1991. Tennessee Department of Agriculture. Tennessee Agricultural Statistics Service. Nashville, Tennessee.

Turner, Eugene R.; Stephen W. Forsythe; Nancy J, Craig. 1981. Bottomland hardwood forest land resources of the Southeastern United States. *In:* Proc. Workshop on Bottomland Hardwood Forest Wetlands of the Southeastern United States. 1980. The Conversation Foundation, National Wetland Technical Council. 13-28p.

U.S.D.A. 1977. Land treatment plan for erosion control and water quality improvement. U.S. Government Printing Office, Fort Worth, Texas. 95 p.

Wells, G.R.; A. Hedlund; J.M. Earles. 1974. Assessment of Tennessee timberland: a guide to implementing the productivity approach. The University of Tennessee. Agricultural Exp. Sta., Bulletin 527.

Insects and Disease/Injury

Moderator:

PAULA SPAINE
USDA Forestry Service

ROOT DISEASE, LONGLEAF PINE MORTALITY, AND PRESCRIBED BURNING

William J. Otrosina, Charles H. Walkinshaw, Stanley J. Zarnoch, Shi-Jean Sung, and Brian T. Sullivan[1]

Abstract–A study was initiated at the Savannah River Site, New Ellenton, SC, to determine factors involved in decline of longleaf pine associated with prescribed burning. Pretreatment and post-treatment surveys were conducted on all treatment plots. Symptomatic trees were recorded by means of a crown rating system based upon symptom severity. Three years after prescribed burning treatments were initiated, mortality and numbers of symptomatic trees increased in the hot burn plots. Crown symptoms corresponded to tree physiological status determined by cambial sucrose synthase activity. Root pathogenic fungi such as *Leptographium terebrantis*, *L. procerum*, and *Heterobasidion annosum* were widespread throughout the study site, regardless of treatment. The *Leptographium* species were found to be pathogenic based upon inoculation experiments and *H. annosum* was observed to be involved in root infections and mortality. Histological studies indicated a high fine root mortality rate in the hot burn treatment. The decline syndrome on these sites is a complex of interacting factors and involves root pathogens, soil factors, root damage, and physiological dysfunction.

INTRODUCTION

Although the beneficial role of fire is well documented for longleaf pine *(Pinus palustris* Mill.), little is known about fire's biological effects, whether prescribed or wild. We do know that a large portion of the above-ground biomass can be altered or lost without significant mortality of seedlings or adult trees. Saplings of longleaf pines are in continuous flush in height growth and are vulnerable to fire and disease (Allen and Scarbrough 1969). On the other hand, field observations report a high mortality rate in adult longleaf pine that continues several years after prescribed burning. Also, recent studies have indicated certain root-infecting fungi such as *Leptographium* species, other Ophiostomatoid species, and *Heterobasidion annosum* (Fr.) Bref. are associated with declining longleaf pine (Otrosina and others 1995, Otrosina 1998, Otrosina and others 1999). This contrasts with the generally held notion that longleaf pine is resistant or highly tolerant to many diseases and insects that adversely affect other southern pine species (Derr 1966, Mann 1969).

Questions arise as to why, in a tree species adapted to frequent fires, are decline and mortality associated with prescribed burning? This study addresses anatomical, pathological, and physiological processes as they relate to fire intensity and identifies areas needing further investigation.

MATERIALS AND METHODS

The study area was selected on the Savannah River Site in Barnwell County near New Ellenton, SC. A 40-year-old planted stand of longleaf pine was subjected to four burning treatments in a randomized complete block design. Each 2.0-ha treatment plot was replicated four times with unburned check, cool, medium, and hot burn intensities randomly assigned. Four 0.0079-ha subplots were located in each plot starting with one at plot center and three others located 30 m from plot center at 120° intervals starting from due north.

Prior to burning, a 100 percent survey was conducted on all plots to document current mortality and symptomatic trees. Burning took place between January and March 1997. Burn temperature was regulated by monitoring fuel moisture sticks, wind speed, and days since precipitation prior to ignition. Temperature data was obtained from max-min thermometers that were placed between the duff layer and mineral soil interface in four evenly spaced locations on each burn plot. The low and medium intensity burns were head fires while the hot burn was a backing fire tending to move more slowly across the landscape. Fuel data by fuel type were obtained according to Savannah River Forest Station fire crew protocols.

Starting one month post treatment and periodically thereafter, 100 percent surveys were conducted on all plots for three years. We employed a slight modification of a crown rating system used previously for longleaf pine symptoms (Otrosina and others 1999). The present rating system consists of five progressively symptomatic crown classes, differing from the previous system by adding a healthy class (class 0) and defining four symptom classes instead

[1]Supervisory research plant pathologist; Research Plant Physiologist, Insititute of Tree-Root Biology, USDA Forest Service, 320 Green Street, Athens, GA 30602; Research Plant Pathologist, Emeritus, #2 Rilwood Circle, Anniston, AL 36207; Mathmatical Statistician, USDA Forest Service, PO Box 2680, Asheville, NC 28802; Research Plant Physiologist, USDA Forest Service, 320 Green St., Athens, GA 30602; Research Entomologist, USDA Forest Service, 2500 Shreveport Highway, Pineville, LA 71360, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

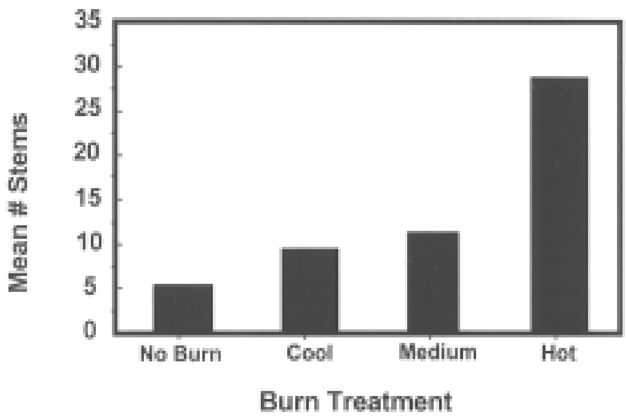


Figure 1a—Mean number of dead longleaf pine stems three years after burn treatments. The hot burn had the largest overall mortality.

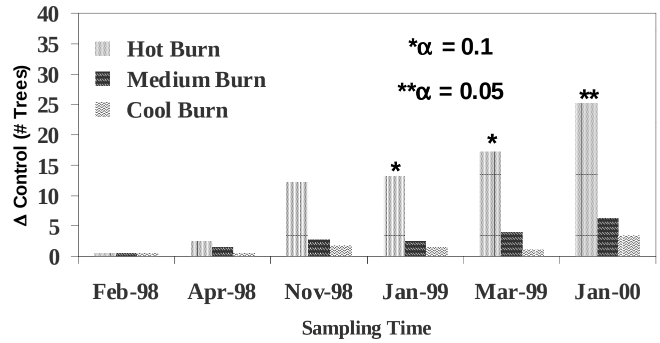


Figure 1b—Mean difference in number of crown symptom class three and four trees between burn treatments and unburned control. A detectable pattern in mortality began to emerge two years after the burn treatments were initiated.

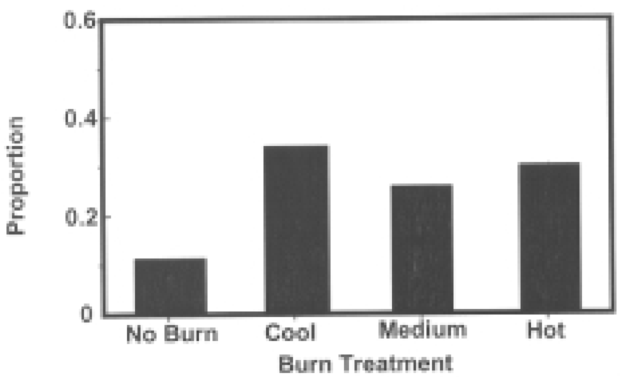


Figure 1c—Mean proportion of trees changing from less severe to more severe crown symptom classes in the three burn treatments and unburned control. All three burn temperatures had a higher proportion of trees with crown class changes than the unburned control.

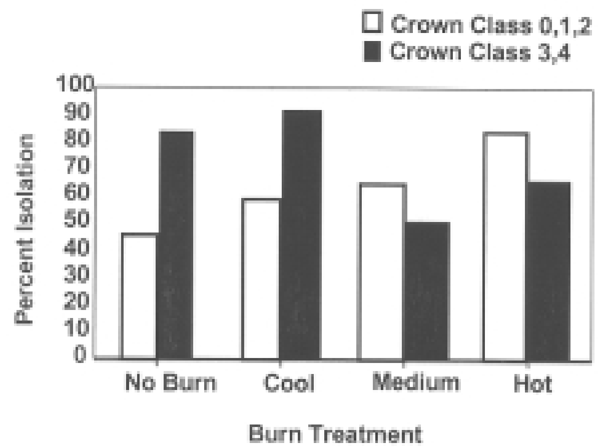


Figure 1d—Percent isolation of *Leptographium* species in woody longleaf pine roots relative to combined (less severe versus more severe) crown symptom classes. Isolation percent is based upon the presence of *Leptographium* species recovered within the total number of trees sampled.

of the three symptom classes used previously. In the present study, we define class 1 trees as those with crowns appearing as slightly off color, although green with less lustrous foliage compared to trees designated as class 0. The remaining three symptom classes are defined as previously reported (Otrosina and others 1999). Mortality and symptomatic trees were tagged and crown symptoms and d.b.h. were recorded.

Randomly selected symptomatic tree woody roots were excavated to approximately 0.5 meters from the root collar. About six root core samples were obtained along the exposed length with a 4-mm diameter increment hammer that penetrated about 2 cm into the xylem. Cores were immediately placed into small plastic bags and then into an ice chest for transport to the laboratory. Core samples were plated onto cycloheximide-amended and unamended 1.25 percent malt extract media, incubated, and evaluated as previously described (Otrosina and others 1999). Pure subcultures were obtained and fungal isolates were identified to genus or species.

Fungal isolates of Ophiostomatoid species obtained from root isolations were used in a pathogenicity study on randomly selected, healthy trees. Isolates of *Leptographium terebrantis, L. procerum, Ophiostoma minus* (used as a positive control), *Leptographium* sp. (resembling *L. serpens*), and an unidentified *Sporothrix* sp. were inoculated onto lower stems (1 m above root collar) and woody roots > 8-cm diameter. Stem bark was shaved to the outer phelloderm with a draw knife or similar blade to allow penetration of a 4-mm-diameter increment hammer to the cambium. Root and stem surfaces were sprayed with 95 percent ethanol prior to wounding. Agar cultures of the isolates were inoculated onto each tree stem and root via 4-mm-diameter agar plugs taken from culture margins. Outer bark retained in the bore of the increment hammer was replaced on the wound. Implements were thoroughly washed in 95 percent ethanol between isolates and inoculation points and each inoculation wound was taped with duct tape and marked for identification.

A stump infection survey was conducted for *Heterobasidion annosum* (Ha) by counting stumps within a 50-m radius circle of each plot center. Within each radial plot, total number of stumps over 10-cm diameter was counted and only those with visible fruiting bodies of Ha were defined as infected. Basidiocarps of Ha that were in good condition were transported to the laboratory for isolation and future study.

During May 2000, five trees from each of the five crown symptom classes were selected at random from hot burn treatment plots to determine stem cambial zone sucrolytic enzymes. A 6-cm by 15-cm section of bark was cut from the stem at breast height to expose cambial tissue. The cambium was scraped with a sharp razor blade and the scraped cambial tissue was then placed in small plastic bags. The bags were immediately submerged in liquid nitrogen contained in a Dewar flask, which served to store the flash frozen cambial tissue until transport to the laboratory for analysis. Analysis of sucrose synthase (SS), ATP-dependent phosphofructokinase (ATP-PFK), and Pyrophosphate-dependent phosphofructokinase (PPi-PFK) was described previously (Otrosina and others 1996).

Within each subplot, a randomly selected tree was used for fine root studies. Four times for each of two years, beginning three weeks after the last burn treatment, soil cores were obtained around the drip line of each selected tree by means of an inertial soil core sampler. Two core samples 6.25 cm in diameter were taken from two depths, 0 to 6 cm and 6 to 12 cm, at opposite positions around the tree. Cored positions were flagged to prevent repeat sampling. Fine roots (< 2-mm diameter) from within organic matter samples (0- to 6-cm depth) were separated from fine roots within mineral soil (6- to 12-cm depth) in the field by screening through a 5-mm mesh screen. Putative root-free soil was retained separately. All samples were placed in an ice chest for transport to the laboratory. Fine roots were oven-dried at 70°C for 24 hr and extracted for ergosterol analysis to estimate living fungal biomass. These procedures have been reported previously (Otrosina and others 1996; Sung and others 1995).

Also, samples of fine roots were taken from the sub-plot trees during March, June, and September of 1997, immediately placed in weak FAA (formalin:acetic acid:alcohol) solution, and were sectioned and stained according to protocols described previously (Walkinshaw and Otrosina 2002). Fine root anatomy was analyzed microscopically and variables such as size and number of starch grains, nuclear condition, tannin accumulation, and root mortality were measured.

Analysis of variance was conducted on tree mortality, crown data, fungal isolation, and fine root variables. The Chi-Square test and Dunnett's treatment versus control test were conducted on data relating to proportions of crown class changes over treatments during the 3-year study period.

Table 1—Proportion of roots in individual trees within the hot burn treatment exhibiting normal anatomy two to six months post burn[1]

	Soil Layer	
Tree	Organic	Mineral
	- - Proportion - -	
1	0.22	0.50
2	0.30	0.33
3	0.00	0.10
4	0.20	0.50
5	0.44	0.50
6	0.00	0.10
7	0.40	0.60
8	0.18	0.30
9	0.10	0.00
10	0.30	0.10

[1]Nine to 12 roots were sampled at random in the two soil layers

RESULTS

Post-Burn Observations

Temperatures from the thermometers placed in each treatment plot registered potentially lethal levels (approximately 130^0 to150^0 F.) in the hot burn treatments only. Spot checks of the duff layer revealed a large amount of decomposed organic matter containing fine roots on all treatments. The decomposed organic layer depth in the cool and medium burn treatment plots was indistinguishable from that of the control plots, indicating very little consumption of this organic matter fraction by the fire in these treatments. The hot burn plots had about one half the decomposed organic matter of the control plots (W.J. Otrosina, unpublished data).

Mortality and Root Infecting Fungi

After nearly three years post-treatment, mean cumulative mortality expressed as number of stems was highest in the hot temperature burn treatment (28.75 stems, $p = 0.06$) (figure 1a). The unburned control had the least mortality (5.5 stems) while the cool and medium treatments had mortality intermediate to the hot and control treatments with 11.25 and 9.5 stems, respectively. Numbers of trees with severe symptoms or mortality (crown class 3 or 4 trees) began to increase in the hot burn treatment with respect to the control plots at about two years post-treatment ($\alpha = 0.1$) (figure 1b), based upon Dunnett's treatment versus control test. At three years post-treatment, the number of trees in these symptom classes increased, exceeding control plot symptomatic tree counts by 25 trees ($\alpha = 0.05$). There were significant differences in proportion of trees that changed from less severe to more severe crown classes among all the burn treatments when compared to the control ($p = 0.039$, Chi-Square = 8.36, 3 df; figure 1c).

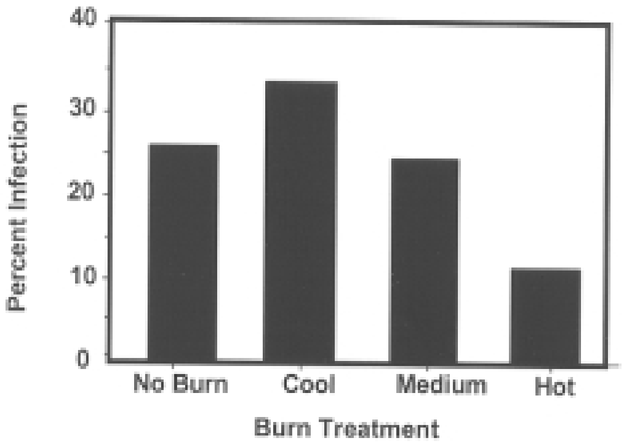


Figure 2—Mean percent of stumps with basidiocarps of *Heterobasidion annosum* within burn treatments. Note the lower percent of stumps with basidiocarps in the hot burn treatment.

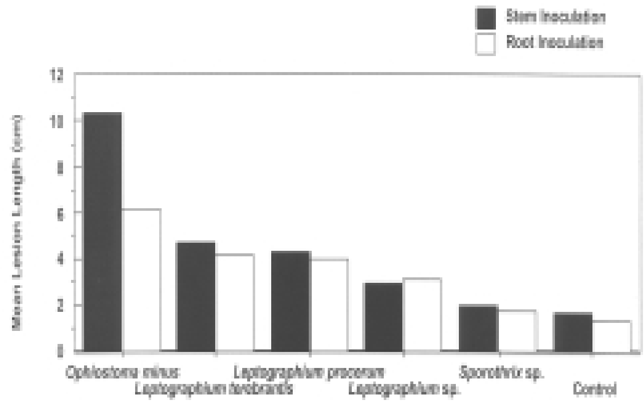


Figure 3—Mean lesion lengths in stems and roots of longleaf pine produced by inoculations with five Ophiostomatoid fungal isolates and a sterile control wound.

Isolations from woody root samples yielded several species of Ophiostomatoid fungi. Among the most common were *Leptographium terebrantis*, *Leptographium procerum*, and a *Sporothrix* sp. These comprised about 80 percent of the isolations from our root samples and no trends were observed in their relative frequencies with respect to burn treatments. The two *Leptographium* species we isolated were widespread throughout the study, regardless of treatment or crown class (figure 1d). On the other hand, *Sporothrix* sp. tended to be isolated more frequently in crown classes 0, 1, and 2.

Heterobasidion annosum Stump Infection

Viable Ha basidiocarps were observed in 7-year-old thinning stumps on our study sites. Eighty-five percent of the basidiocarps were found inside tangential splits in the sapwood caused by thinning equipment. These splits occurred within the outer 8 cm of the stumps and extended downward to the soil line. Infected stumps were widespread throughout the study site and all sampled plots yielded active basidiocarps. The percentage of stumps with active basidiocarps ranged from 7 percent to 51 percent over all treatments. The hot burn treatment had a mean proportion of 0.13 infected stumps, less than the control, cool, and medium burn treatments ((figure 2) ($p = 0.1$)).

Stem and root inoculations

Significant differences in cambial zone lesion length ($\alpha = 0.05$) were found among the fungal isolates tested for pathogenicity (figure 3). *Ophiostoma minus* produced the longest lesions, followed by *L. terebrantis* and *L. procerum*. An unidentified *Leptographium* species, resembling *L. serpens*, also produced a lesion that was significantly longer than the control wound. The lesion produced by an unidentified *Sporothrix* species was slightly longer than the control wound but statistically indistinguishable from it. Roots tended to have significantly smaller lesion lengths than stem inoculations overall ($\alpha = 0.05$).

Stem cambial zone sucrolytic enzymes

Regressions of enzyme specific activities with respect to the five symptom severity classes as independent variables for SS, PPi-PFK, and ATP-PFK indicated decreasing enzyme activities associated with increasing symptom severity (SS = -26.5Z +133, PPi-PFK = -30.3Z+157.8, and ATP-PFK = -10.7Z + 68.7; $p = 0.0001$, $R^2 = 0.53$, 0.42, and 0.44, respectively).

Fungal Biomass Estimates

Ergosterol analysis to estimate live fungal biomass indicated a higher concentration in the soil organic layer root clumps (figure 4) when compared to the other three soil fractions. These organic matter root clumps ranged from 16 to 49 µg/g ergosterol (dry weight basis). Also, these values were consistent over the two-year sampling period. In contrast, root-free soil had the least ergosterol over all sampling intervals. Root clumps in the soil and root free organic matter had intermediate amounts of ergosterol (range 5-15 µg/g dry weight). We did not detect clear treatment effects with respect to ergosterol concentration, although overall values in burn plots tended to be higher in the first year post-treatment than in the second year.

Fine-Root Anatomy and Mortality

Proportion of roots in the hot burn exhibiting normal anatomy two to six months post-treatment is given in table 1. The organic layer root mortality ranged from 56 percent to 100 percent. Root samples collected from the mineral layer had 40 percent to 100 percent mortality. No significant differences were found for root mortality between the two soil fractions, nor was fine root diameter or starch content related to mortality ($r^2 = 0.09$ and $r^2 = 0.30$, respectively). On the other hand, histological analysis of roots from mineral soil indicate a significant relationship between number of cortical cell starch grains and root mortality for the control and cool burn treatments ($r^2 = 0.73$ and 0.75, respectively) (figure 5). We found no relationship between number of cortical cell starch grains and root mortality in the medium and hot burn treatment ($r^2 = 0.02$ and 0.05, respectively).

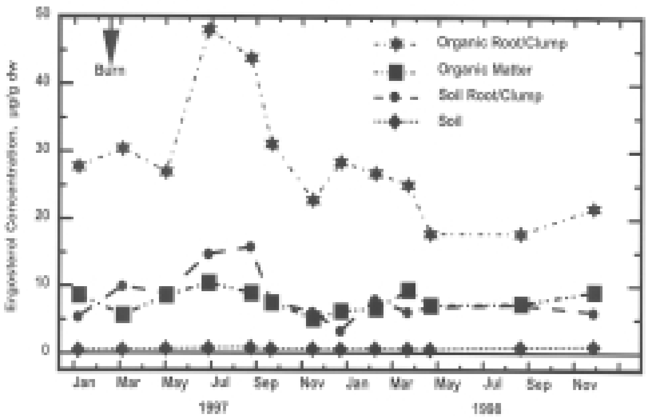


Figure 4—Below-ground distribution of live fungal biomass expressed as mean ergosterol concentrations in four soil or organic matter fractions. Sampling was done periodically over 18 months after beginning of the burn treatments. Symbols represent ergosterol concentrations of a given soil fraction at the specific sample date.

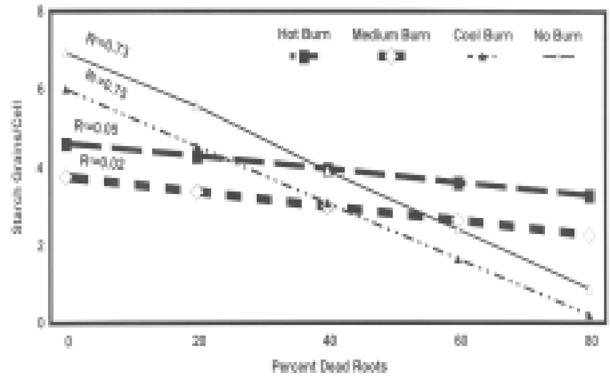


Figure 5—Regression relationship between root death and number of starch grains in fine root cortical cells. An inverse relationship exists between number of starch grains and percent dead roots in the hot and medium burn treatments. No relationship between root death and starch grains was detected in the cool burn and control treatments.

Dead roots often retained their bark cells in tight multicellular layers that resisted tearing when sectioned. When viewed macroscopically, these roots were often confused with undamaged, live ones. Sectioning and staining these roots revealed extensive internal damage. Large numbers of starch grains were trapped within necrotic cells, the cambium was disorganized, and nuclei stained abnormally. Bark formation and persistence of roots in burned plots was normal, as active formation of bark cells occurred in 64 percent of roots from burned plots and 58 percent of roots from unburned plots. Excess tannin accumulated in 65 percent of the roots from the burn plots and in only 12 percent of those from the unburned plots. Hydrolysis of cortical cell contents was limited in the burn plot samples and starch grains were intact. Cell wall structure, the cambium, and nuclei appeared to be preserved by released tannin.

DISCUSSION

The trend toward increasing mortality over time is evident in the hot burn treatment. Mortality onset is delayed in the burn treatments for at least two years, based upon our data (figure 1a). By the third year, clear separation between the hot burn treatment and unburned control plots, and the other burn treatments, is evident. Even the cooler burn treatments, while having less mortality, tended to have more trees progress from less severe to more severe crown symptoms when compared to the control (figure 1b). Thus, mortality cannot be ascribed to direct heat effects such as cambial scorching. Further evidence for indirect effects of the hot burn is the onset of decline symptoms that precede mortality, suggesting physiological and pathological causes. Regarding the physiological basis for the decline syndrome, analysis of SS activity is a quantitative indicator of tree stress (Sung and others 1993, Otrosina and others 1996) and corresponds well to the crown symptom classification we established. This suggests our visual crown evaluations approximate tree physiological status as defined by SS activity.

The mechanism driving this decline and mortality appears very complex. In this study, the term “hot burn” is relative and must be taken in context. In the hot burn treatment, about one half the amount of post-burn, decomposed organic matter containing fine roots still remained. This fact may provide clues toward understanding the mechanism as to why such mortality is triggered by fire. One hypothesis is that infrequent prescribed fire intervals allowed buildup of this decomposed organic matter containing fine roots. These roots are then susceptible to indirect heat effects. Our data on root anatomy show that fine roots can be damaged by heat without being consumed and without showing obvious macroscopic damage. Cortical cell starch grains were intact and their numbers were not associated with root mortality in the hot and medium burn treatment (figure 5). In dead fine roots, we observed limited hydrolysis of cortical cell contents, intact cell wall structure, and abundant intact achromatic nuclei in these burn plot samples, presenting further evidence of rapid cell death as would occur under a lethal pulse of heat. In contrast, there is an inverse relationship between numbers of cortical cell starch grains and root mortality in the mineral soil of the unburned and cool burn treatments (figure 5), indicating a relatively slower physiological process taking place in fine roots where their exposure to high temperatures is limited (Walkinshaw and Otrosina 1999). On the other hand, root death due to direct heat effects in mineral soil is somewhat enigmatic. Soil does not conduct heat efficiently, although steam can conceivably penetrate short distances through soil pores. We observed some interconnections between finer roots in the organic layers and the mineral soil and thus, damage to roots above may effectively cutoff roots in lower soil layers. Also, damage to larger woody lateral roots near the surface can affect more distal fine roots.

We found the highest portion of living fungal biomass in the fine root clumps of the organic layer (figure 4). Because the organic layer fine root clumps are presumed largely comprised of ectomycorrhizal fungi, and some studies indicate fine root production and associated symbiotic fungal biomass may account for two-thirds of the annual biomass production in some forest types (Marshall and Waring 1985), heat damage to this root fraction can result in significant stress.

Another element driving mortality may be facultatively pathogenic fungi. We found Ophiostomatoid species such as *Leptographium terebrantis*, *L. procerum*, and *Sporothrix* sp. to be widespread in woody roots regardless of treatment or crown condition (figure 1d). Because these fungi are adapted to insect dissemination, and little is known about the root feeding bark beetle species that are involved in their spread, critical interactions between insects and these fungi probably occur. Other studies have associated these fungi with insect attack, mortality, or decline symptoms in loblolly pine and longleaf pine stands (Otrosina and others 1997, Otrosina and others 1999). Longleaf pine are generally regarded as resistant or highly tolerant to root disease fungi and reports of Ophiostomatoid fungi attacking woody roots of longleaf pine, other than Otrosina and others (1999), are few. In our inoculation experiment, we demonstrated pathogenicity of these Ophiostomatoid species (figure 3) on longleaf pine and thus established their association with observed decline symptoms. The fact that Ophiostomatoid fungi are widespread begs the question as to their specific role. We recovered these fungi from both asymptomatic trees and declining trees regardless of treatment or crown condition. In asymptomatic trees, we isolated *L. terebrantis*, *L. procerum,* and unidentified *Leptographium* and *Sporothrix* species from both symptomatic roots and roots exhibiting no resinosis or staining, although symptomatic trees tended to have more resinous roots than non-symptomatic trees. Resinous lesions in roots signify an active defense by the tree against the pathogen, diverting energy resources to the infection site. If under stress, this can result in significant loss of growth and maintenance functions and may account for decline symptoms. *L. procerum* can survive in pine woody tissues for some time without causing obvious symptoms (Horner and others 1987) and Bannwart (unpublished MS thesis, University of Georgia Department of Plant Pathology 1998) found that *L. procerum* and *L. terebrantis* can survive in callused stem lesions of longleaf pine seedlings. Also, evidence suggesting the presence of *L. terebrantis*, *L. procerum*, and other Ophiostomatoid species in roots is a stress indicator in longleaf pine and loblolly pine stands has been presented (Otrosina and others, 1997, Otrosina and others 1999). Thus, the occurrence of root infecting *Leptographium* species may contribute to the decline syndrome after an additional stressor, such as fire damaged fine roots, is introduced in an already stressed system. Given these biological circumstances, fungi that are not regarded as pathologically important can cause significant and unexpected damage.

Other root pathogens such as Ha have not been regarded as important in longleaf pine because of its tolerance or resistance to this pathogen. We found the fungus to be widespread in our study, judging by stump infection (figure 2) and by observations of trees infected by Ha throughout our study. The pathogen was an important factor in longleaf pine decline in another area on the Savannah River Site (Otrosina and others 1999). Because Ha infection in longleaf pine is not often reported as a problem, infected trees we observed in this study may be another sign of complex pathological interactions involved. Infected stumps in our study continued to produce basidiocarps at least seven years after the last thinning, although stumps in the hot burn plots had produced less basidiocarps than stumps from all other treatments. Unlike Ophiostomatoid fungi, Ha decomposes woody root tissues and can persist for long periods of time in infected stumps and roots because it is highly adapted to resinous wood (Otrosina and Cobb 1989). Longleaf pine stumps are highly resinous and resist decomposition for a long period of time. When healthy tree root systems contact colonized stump roots or roots from infected living trees, the fungus spreads from tree to tree causing mortality and downed trees from disintegration of structural roots. Once present in a stand, this fungus can become a recalcitrant problem. We found infected stumps as small as 12 cm in diameter, demonstrating the importance of applying borax formulations to freshly cut stump surfaces to prevent infection from airborne Ha basidiospores.

The longleaf pine decline associated with prescribed burning on this study site cannot be attributed to a specific cause. We described a complex of interacting factors implicating fire intensity, fine root damage, *H.* annosum, Ophiostomatoid fungi, and physiological dysfunction. Soil type and stand density are also important components involved in this syndrome that require investigation. Certainly, fire dependent ecosystems should be regarded as exotic ecosystems (Otrosina 1998) when fire reintroduction after a long period of fire suppression is contemplated. Under these circumstances, fire reintroduction must be conducted with caution and consideration must be given to below ground pathological and physiological processes.

ACKNOWLEDGMENTS

The Authors thank the Savannah River Forest Station, USDA Forest Service, for funding this project. We also thank the Savannah River Forest Station fire crews for their attention to our study requirements that resulted in excellent application of the prescribed burn treatments on our study plots.

LITERATURE CITED

Allen, R.M.; Scarbrough, R.M. 1969. Development of a year's height growth in longleaf pine saplings. USDA Forest Service Research Paper SO-45. 13 p.

Derr, H.J. 1966. Longleaf X Slash hybrids at age 7: survival, growth, and disease susceptibility. Journal of Forestry. 230-236.

Horner, W.E.; Alexander, S.A.; Lewis, K.J. 1987. Colonization patterns of *Verticicladiella procera* in Scots and eastern white pine and associated resin-soaking, reduced sapwood moisture content and reduced needle water potential. Phytopathology. 77: 557-560.

Mann, W.F. 1969. At last- longleaf pine can be planted successfully. Forest Farmer. 28: 6-7, 18-19.

Marshall, J.D.; Waring, R.H. 1985. Predicting fine root turnover by monitoring root starch and soil temperature. Canadian Journal of Forest Resources. 15: 791-800.

Otrosina, W.J. 1998. Diseases of forest trees: consequences of exotic ecosystems? In Waldrop, Thomas A., ed. Proceedings of the ninth biennial southern silvicultural research conference; 1997 February 25-27; Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC, U.S. Department of Agriculture, Forest Service, Southern Research Station: 103-106.

Otrosina, W.J.; Bannwart, D.; Roncadori, R.W. 1999. Root-infecting fungi associated with a decline of longleaf pine in the southeastern United States. Plant and Soil 217:145-150.

Otrosina, W.J.; Cobb, F.W., Jr. 1989. Biology, ecology, and epidemiology of *Heterobasidion annosum*. In: Otrosina, W.J.; Scharpf, R.F., tech. coords. Proceedings of the symposium on Research and Management of Annosus Root Disease (Heterobasidion annosum) in western North America; 1989 April 18-21; Monterey, CA. Gen Tech Rep. PSW-116. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 26-33.

Otrosina, W.J.; Hess, N.J.; Zarnoch, S.J. [and others]. 1997. Blue-stain fungi associated with roots of southern pine trees attacked by the southern pine beetle, *Dendroctonus frontalis*. Plant Disease. 81: 942-945.

Otrosina, W.J.; Sung, S.S.; White, L.M. 1996. Effect of subsoiling on lateral roots, sucrose metabloizing enzymes, and soil ergosterol in two Jeffrey pine stands. Tree Physiology 16:1009-1013.

Otrosina, W.J.; White, L.M.; Walkinshaw, C.H. 1995. Heterobasidion annosum and blue stain fungi in roots of longleaf pine are associated with increased mortality following prescribed burning [Abstract]. Phytopathology. 85: 1197.

Sung, S.S.; Kormanik, P.P.; Black, C.C. 1993. Vascular cambial sucrose metabolism and growth in loblolly pine in relation to transplanting stress. Tree Physiology. 12: 243-258.

Sung, S.S.; White, L.M.; Marx, D.H.; Otrosina, W.J. 1995. Seasonal ectomycorrhizal fungal biomass development on loblolly pine (*Pinus taeda* L.) seedlings. Mycorrhiza. 5: 439-447.

Walkingshaw, C.H.; Otrosina, W.J. 1999. Cellular pathology of longleaf pine roots subjected to high temperatures during prescribed burns [Abstract]. Phytopathology. 89(6): S89.

Walkingshaw, C.H.; Otrosina, W.J. 2002. Food reserves in mountain longleaf pine roots during shoot elongation. [This proceedings].

ASSESSMENT OF LOBLOLLY PINE DECLINE IN CENTRAL ALABAMA

Nolan J. Hess, William J. Otrosina, Emily A. Carter, Jim R. Steinman, John P. Jones, Lori G. Eckhardt, Ann M. Weber, and Charles H. Walkinshaw[1]

Abstract—Loblolly pine (*Pinus taeda* L.) decline has been prevalent on upland sites of central Alabama since the 1960's. The purpose of this study was to compare Forest Health Monitoring (FHM) standards and protocols with root health evaluations relative to crown, stem, and site measurements. Thirty-nine 1/6 acre plots were established on loblolly decline sites in nine central Alabama counties. Sites were selected on federal, state, and private industrial lands to measure variables of decline symptoms, age classes and management procedures. A two-root sampling procedure, selective media, and soil baiting assay methods were used to isolate pathogenic root infecting fungi. Pitfall traps collected root-feeding insects from which *Leptographium* species were recovered. FHM indicators of tree crown conditions were recorded on all pines in the plots. Preliminary results showed a significant correlation between live crown ratio and incidence of *Leptographium* spp. We recovered *Leptographium* from damaged roots in eighty-four percent of plots. The pine basal area was significantly reduced with increased incidence of *Phytophthora cinnamomi* Rands, with *P. cinnamomi* being recovered from the soil root zone in 50 percent of the plots. Histological examination of root damage indicated a significant correlation between reduced growth and root wounding.

INTRODUCTION

A decline of loblolly pine, *Pinus taeda* L., has been observed on the Talladega National Forest in central Alabama since 1959 (Brown and McDowell 1968). The decline condition was initially referred to as "loblolly pine die-off," and was most frequent in sawtimber-size trees over age 50. During the 1960's and 1970's, studies were initiated to determine the cause of the die-off and the rate of spread. Twenty-four plots were established in loblolly pine stands on the Oakmulgee District to assess decline and mortality. Soil and root samples were analyzed for the presence of root pathogens including *Phytophthora cinnamomi* Rands, a primary factor in the development of littleleaf disease. There was some recovery of *P. cinnamomi* from the decline plots, but it was reported that root system deterioration of the die-off trees was more extensive than that found in littleleaf diseased trees (Brown and McDowell 1968). Although a specific cause was not determined, several observations and conclusions came out of this study. Lateral root deterioration preceded the presence of observable foliage symptoms. Symptoms included sparse crowns, chlorotic needles, reduced radial growth at age 40-50, and heavy cone crops occurring prior to mortality. Mortality occurred 2 to 6 years after onset of symptoms. Also, a large percentage of the fine roots died before tree mortality occurred (Brown and McDowell 1968).

The decline symptoms were most severe on the Oakmulgee Ranger District near Centreville, AL, which falls within the Upper Gulf Coastal Plain Province. During the 1940's and 1950's, other surveys in the Upper Coastal Plain reported damage to shortleaf pine (*Pinus echinata* Mill.) stands caused by littleleaf disease. This disease was strongly associated with *P. cinnamomi* on sites with low fertility and poor internal drainage (Campbell and Copeland 1954, Roth 1954). Loblolly pine was also affected by littleleaf disease when associated with diseased shortleaf pine sites (Campbell and Copeland 1954).

The forests of the Oakmulgee were predominately longleaf pine (*Pinus palustris* Mill.) during the pioneer settlement era of the early 1800's. From 1908 until 1929, most of these trees were harvested for lumber, and the land was converted to agricultural use. During the 1930's and 1940's, federal acquisition programs relocated farm families and established National Forests (Johnson 1947). Abandoned farmland then regenerated to loblolly pine and shortleaf pine.

Management recommendations from the 1960's and 1970's for the Oakmulgee Ranger District were to prevent decline situations by reducing the rotation age of loblolly pine stands from 70 to 60 years and by maintaining basal area at 60 to 70 ft² per acre. Recommendations also

[1]Plant Pathologist, USDA Forest Service, Pineville, LA; Research Plant Pathologist, Southern Research Station, Athens, GA; Research Soil Scientist, Southern Research Station, Auburn, AL; Research Forester, USDA Forest Service , Asheville, NC; Professor, Graduate Student, Research Associate, Louisiana State University, Baton Rouge, LA; and Emeritus Scientist, USDA Forest Service, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1—Number of plots by location, physiographic region, and land management ownership

Number of Plots	Soil Physiographic Regions Of Alabama	County	Land Management Ownership
9	Piedmont	Clay, Cleburne, Talladega	Talladega National Forest (Federal)
5	Ridge & Valley	Calhoun	Choccolocco State Park (State)
16	Coastal Plain	Bibb, Hale, Chilton, Perry	Talladega National Forest (Federal) (Oakmulgee R.D.)
9	Cumberland Plateau	Tuscaloosa	Gulf State Paper Corporation (Private-Industrial)

included the conversion of declining loblolly pine stands to longleaf pine. To date, approximately 20,000 acres have been converted to this species. However, there are still about 40,000 acres of loblolly stands on the Oakmulgee District in various stages of decline. A recent biological evaluation of decline sites on this District found that *P. cinnamomi* and *Pythium* sp. are predominant pathogens associated with loblolly pine fine root deterioration (Hess and others 1999).

Other areas of central Alabama have reported loblolly decline, including National Forest lands in the Anniston/Heflin area of Alabama (Hess 1997). Forest industry land managers reported declining loblolly stands in Tuscaloosa and Bibb Counties (Allen 1994). Loblolly pine decline on littleleaf diseased sites on two National Forests within the Piedmont Physiographic Region of South Carolina has been found (Oak and Tainter 1988). In addition, loblolly pine decline associated with *P. cinnamomi* and *Pythium* species was also reported in Louisiana (Lorio 1966).

Since its inception in 1990, Alabama has participated in the USDA Forest Service's Forest Health Monitoring (FHM) Program. A main objective of this program is to develop and implement standards and protocols for assessing conditions of forest resources. Preliminary analyses of FHM (P3) plots and other survey data collected in Alabama and other southern states from 1995 through 1997 identified 30 percent of loblolly pine stands as having decline symptoms (Steinman and others 2000). This FHM Evaluation Monitoring Project represents further investigation of causal agents associated with the decline of loblolly pine within central Alabama. The purpose of this study was to compare the presence of pathogens in roots and soil with tree growth and FHM indicators on loblolly pine decline sites.

METHODS

Plot Description

Sites for plot establishment were selected on federal, state, and private industrial lands. Thirty-nine 1/6 acre sample locations in nine central Alabama counties were selected in the spring of 2000. Plot establishment followed the FHM guidelines (Dunn 1999), using a cluster of four 1/24 subplots. The plot locations fell within four Physiographic Regions of Alabama: the Piedmont, Ridge and Valley, Upper Coastal Plain, and Cumberland Plateau (table 1). At each location, root health assessment was accomplished by selecting three dominant, or co-dominant, symptomatic pines nearest the plot center of the center subplot. Root sampling was done with the modified two-root excavation method (Otrosina and others 1997).

Radial growth was measured by obtaining an increment borer core at breast height (BH) of each of the sample trees. With the aid of hand lenses, increment cores were measured for five and ten year radial growth increments and age.

FHM Indicators of Tree Crown Conditions

Tree crown conditions were measured on all pine trees (DBH $\geq$ 5.0) within all 39 plots. The crown measurements included live crown ratio, crown light exposure, crown density, crown dieback, and foliage transparency. Live crown ratio is a measure of crown length and its relationship to total tree height. Crown light exposure and crown position are combined in analysis to determine stand and canopy structure. Once the live crown ratio, crown light exposure, and crown position are determined, the next step is to measure how much of a crown exists. Crown density, which includes foliage, branches and reproductive structures, measures the crown biomass. Crown dieback defines how much of the crown does not have foliage but has fine twigs, indicating a loss of vigor or growth potential. Foliage transparency estimates how dense the foliage is on branches, indicating a loss of vigor or stress due to foliage damage or defoliation (USDA Forest Service 2000).

Insect Interactions

Pitfall traps were installed on 15 of the 39 plots, and insects collected weekly from April 17^{th} to June 5^{th}, 2000. Traps were constructed of 20 cm lengths of 10 cm

Table 2—Sample plot means of tree measurements by types of forest ownership

Measurements	Public (n = 30 plots) Mean	S.E.	Industry (n = 9 plots) Mean	S.E.	Probability
All overstory pine trees					
Stand age (years)	46	2	36	2	0.0265
Total pine basal area (ft²/acre)	69.3	3.4	63.3	7.1	0.41
DBH (inches)	10.0	0.3	10.2	0.5	0.76
Live crown ratio (pct)	38	1	41	1	0.17
Foliage transparency (pct)	32	0	29	1	0.00
Crown dieback (pct)	1	0	0	0	0.67
Crown density (pct)	39	1	40	2	0.70
Plot sample trees					
DBH (inches)	11.4	0.5	11.0	0.7	0.67
Last 5-yr basal area increment (ft²)	0.09	0.01	0.11	0.02	0.18
Last 10-yr basal area increment	0.18	0.02	0.20	0.02	0.42
Live crown ratio (pct)	37	1	41	2	0.10
Foliage transparency (pct)	31	1	29	1	0.05
Crown dieback (pct)	1	0	0	0	0.71
Crown density (pct)	39	1	39	1	0.85

diameter drainpipe with eight entrance holes spaced around the pipe. The interior of each trap was coated with liquid Teflonä to prevent insect escape. Ends were capped with plastic lids and two holes were drilled in the bottom end for drainage. Traps were placed so that the entrance holes were slightly above ground level. Each trap was baited with two 8 ml glass vials, one containing 95 percent alcohol and one containing turpentine. Two freshly cut pine stems were also placed inside the traps (Klepzig and others 1991). Trapped insects were placed in sterile polyethylene specimen cups and maintained for two to three days at 4°C until isolations could be made. Insects were inventoried and rolled across cycloheximide-streptomycin amended malt extract agar (CSMA—2 percent MEA containing 800 ug/ml of cycloheximide and 200 ug/ml of streptomycin sulfate) and unamended malt extract agar (MEA) (Hicks and others 1980). Agar plates were incubated at 25°C and colonies resembling *Leptographium* were transferred to sterile plates or slants of MEA.

Processing Roots

Two primary roots from each sample tree were excavated using hand tools, beginning at the root collar and extending out to the tree drip line. The primary roots were then cut from the tree and removed. All soil samples were collected adjacent to the roots.

Root samples were collected during April, May, and June of 2000. The fine roots from each primary root were excised, bagged, labeled and maintained in the field on ice. The

Table 3—Correlations between crown vigor associated with plot sample trees

	Crown dieback (pct)	Crown Density (pct)	Foilage Transparency (pct)	Live Crown Ratio (pct)	BAI[1] Last 5 years (ft²/tree)	BAI Last 10 years (ft²/tree)
	- - - - - - - - Pearson correlation coefficient - - - - - - - -					
	- - - - - - - Probability of significance - - - - - - -					
BAI last 5 years	-0.15	0.38	-0.20	0.54		
(ft²/tree)	0.36	0.02	0.21	0.00		
BAI last 10 years	-0.23	0.43	-0.10	0.49		
(ft²/tree)	0.15	0.01	0.52	0.00		
Pine basal area	-0.10	-0.15	-0.19	-0.04	-0.27	-0.24
(ft²/acre)	0.55	0.35	0.25	0.79	0.09	0.13
Stand basal area	-0.06	-0.14	-0.02	-0.11	-0.25	-0.19
(ft²/acre)	0.71	0.40	0.88	0.50	0.13	0.26

[1] BAI = basal area increment

Table 4—Sample plot means of tree measures of vigor by incidence of *Leptographium* spp

Measurements	Incidence of *Leptographium* in roots or soil 0 pct (n = 4 plots) Mean	S.E.	33 pct (n = 8 plots) Mean	S.E.	67 pct (n = 16 plots) Mean	S.E.	100 pct (n = 11 plots) Mean	S.E.	F Probability
Total pine basal area (ft²/acre)	73	16	70	7	63	3	73	6	0.52
Last 5-yr basal area increment (ft²)	0.11	0.04	0.10	0.01	0.09	0.01	0.07	0.01	0.32
Last 10-yr basal area increment (ft²)	0.20	0.05	0.20	0.02	0.20	0.02	0.15	0.02	0.34
DBH (inches)	12.4	1.9	11.1	0.7	11.2	0.6	11.4	1.0	0.86
Crown dieback (pct)	1	1	0	0	0	0	1	1	0.14
Crown density (pct)	38	2	41	2	41	1	37	2	0.24
Foliage transparency (pct)	29	1	29	1	32	1	30	1	0.14
Live crown ratio (pct)	42	3	42	2	37	2	35	1	0.06

primary roots were also randomly chipped or cut into pieces, bagged, labeled, and iced for transportation to the laboratory. Roots were excavated from 117 trees, with 234 primary roots sampled, along with collections of fine roots and soil samples from the root zones. Root samples for isolation of fungi from primary and fine roots were transported to Louisiana State University, Plant Pathology Laboratory, Baton Rouge, LA.

Isolation of Microorganisms

Phytophthora spp. and *Pythium* spp. were isolated from fine roots and soils using three methods. The first method used the selective medium PARP(H) (Ferguson and Jeffers 1999). Eight to ten pieces of fine roots (< 2mm diameter) were washed, dried, cut into 2 cm lengths, and plated on PARP(H). The specimens were incubated in the dark at 20°-25°C for 3 days. Subcultures were established from *Phytophthora*-like fungi growing from the roots. The second method of isolating was soil assay. Soil samples were assayed from a soil suspension on PARP(H) (Jeffers 2000). The plates were examined for *P. cinnamomi* after incubation for 48 to 72 hours in the dark. A third isolation method employed for *Phytophthora* and *Pythium* species was baiting. Soil samples collected during root excavation were incubated in Petri plates with fresh camellia, juniper, or pine stems (Jeffers 2000). Plates were incubated at 24 and 72 hours, after which we checked for characteristic *Pythium* or *Phytophthora* sporangia.

Isolation of Ophiostomatoid fungi from primary roots utilized selective media. Roots were cut into small pieces, rinsed in tap water, decontaminated in 10 percent commercial bleach, treated with 10 percent ethanol solution for one minute, rinsed again in tap water for three minutes, and blotted dry. Four pieces were placed in a Petri plate containing selective medium (CSMA) to isolate *Leptographium* species. Plates were incubated at 25°C and *Leptographium* isolates were subcultured from hyphal tips and conidial heads onto MEA. Subcultures were maintained in MEA slants and stored at 8°C until identified.

Table 5—Sample plot means of tree measures of vigor by incidence of *P. cinnamomi*

Measurements	-----Incidence of *P. cinnamomi* in roots or soil----- 0 pct (n = 19 plots) Mean	S.E.	33 pct (n = 12 plots) Mean	S.E.	67 pct (n = 5 plots) Mean	S.E.	100 pct (n = 3 plots) Mean	S.E.	F Probability
Total pine basal area (ft²/acre)	80	4	55	4	56	5	63	9	0.00
Last 5-yr basal area increment (ft²)	0.09	0.01	0.10	0.02	0.08	0.01	0.11	0.04	0.70
Last 10-yr basal area increment (ft²)	0.18	0.02	0.19	0.03	0.18	0.01	0.20	0.07	0.96
DBH (inches)	11.8	0.6	11.1	0.8	10.5	0.7	11.3	2.1	0.8
Crown dieback (pct)	0	0	1	0	0	0	1	1	0.77
Crown density (pct)	39	1	39	2	39	4	41	2	0.95
Foliage transparency (pct)	30	1	31	1	33	2	30	3	0.55
Live crown ratio (pct)	38	1	38	2	39	2	34	6	0.72

Soil samples were analyzed for *Leptographium* sp. by removing a 10 g aliquot from thoroughly mixed soil previously collected near lateral roots. Root fragments were removed from the aliquot by sieving and suspending them in 40 mls of sterile, 0.5 percent water agar. One milliliter of this suspension was pipetted into ten petri dishes containing 10 mls of CSMA. Dishes were incubated at 25°C and examined daily for the presence of fungus. Isolates were transferred to MEA slants and stored at 8°C until they could be identified.

Root Damage Assessment

During the root excavation and sampling procedures, a sub-sample of 17 plots was chosen to evaluate fine root damage through histological examination. Random samples of unwashed fine roots were taken from the primary roots and placed in formalin/acetic acid/alcohol fixative (FAA) for 14 days (Sass 1951). Fixed root specimens were cut to 1 to 3 mm, dehydrated in an alcohol series, embedded in paraffin, and sliced into 7 to 10 µm transverse sections. Slides were stained with a variety of schedules, including Papanicolaou's hemotoxylin-eosin or an acid-Schiff procedure (Hass 1980, Horobin and Bancroff 1998). Stained sections where observed under a light microscope and then catalogued into damage categories (Walkinshaw and Tiarks 1997, Walkinshaw and others, 2001).

Data Analysis

Measures of stand structure, tree growth, and tree crown and damage conditions were used to summarize decline symptoms of loblolly pine for each plot. Values were compared between the 30 plots located on public land and the 9 plots on industrial ownership to determine if the presence of decline symptoms was related to different types of forest management these ownerships represent. Data were analyzed using T-tests.

Correlations between continuously scaled measurements of stand structure, crown conditions, radial growth, and root conditions were also calculated. These summaries were used to interpret physiological and pathological relationships among different indicators that express decline symptoms. We used the percentage of the three sample trees on each plot with pathogens present to define four categorical levels of pathogen incidence (0, 33, 67, or 100 percent). We then compared plot values for stand structure, tree growth, and tree crown conditions among the categories of pathogen incidence by analyses of variance.

Proportions of damaged roots, root mortality, and number of starch grains in cortical cells were recorded from histological examinations and paired with tree growth and crown variables. Correlations and regression analysis were conducted on these data (Walkinshaw and Otrosina 2001).

RESULTS

Analysis of tree crown condition indicators of the 39 sample plots, compared to the other loblolly pine Forest Health Monitoring plots, shows a difference in transparency of the tree crowns. Transparency (the amount of light filtering through the foliated portion of the tree crown) was considerably greater for our sample plots, as would be expected, as crowns decline and become sparse. Foliage transparency was greater on public land (table 2). Stand age on public land was ten years older than that of industrial land. Tree crown condition indicators showed a significant correlation between DBH growth, crown density, and live crown ratio (table 3). Live crown ratio was less on plots having a greater incidence of *Leptographium* sp. (table 4). On a plot basis, the incidence of *Leptographium* sp. from roots of the 39 sample plots was 84 percent from roots, and 33 percent from soils. Overall *Leptographium* isolation percentage was greater on public lands (93 percent) when compared to industrial lands (55 percent).

Using baiting procedures, *Phytophthora cinnamomi* was isolated from soils in 50 percent of the plots on public land and slightly higher on industrial land (55 percent). *P. cinnamomi* was not recovered from root isolations. Plots with *P. cinnamomi* had less pine basal area than those those plots where *P. cinnamomi* was not found by soil baiting (table 5).

Microscopic examination of 700 fine root pieces from the 17 selected plots showed high incidence of root injury and mortality. The number of starch grains in the cortical cells was reduced and the disposition of tannin was excessive (Walkinshaw and others 2001). The inverse relationship between proportion of roots with injuries and radial growth of the cambium in the last 5 years was significant ($r^2 > 0.50$). Damage to resin canals was also a useful variable in the interpretation of microscopic data (Walkinshaw and others 2001) and was consistent with the observed root pathological status.

DISCUSSION AND CONCLUSIONS

The majority of the plots in this study had trees with decline symptoms, and assessment of woody roots, fine roots, and soil demonstrated the presence of root pathogenic fungi. The results of this assessment are consistent with the observations of Brown and McDowell (1968) who characterized fine root deterioration in 40 to 50 year-old trees prior to the onset of severe decline symptoms. A notable difference between their study and ours lies in the recovery of pathogenic root infecting fungi. Isolation and detection procedures for Pythiaceous and Ophiostomatoid fungi from roots and soil have become more efficient since the Oakmulgee studies of the 60's and 70's (Tainter and Baker 1996). Even though the edaphic parameters of this assessment are not complete, the abundant recovery of *Leptographium* sp. and *P. cinnamomi* from primary woody and fine roots, respectively, and the associated soils, coupled with the ability to evaluate the crown symptoms with established FHM protocols, help to further define the components of loblolly pine decline. *Leptographium* species are associated with pine decline and mortality in connection with root-feeding beetles and weevils that attack living trees (Harrington and Wingfield 1977, Otrosina and others 1997). Hess and others (1999) concluded that *P. cinnamomi* and *Pythium* sp. appeared to be the primary pathogens associated with the deterioration of loblolly pine fine root systems on the Oakmulgee. Although *P. cinnamomi* is considered a primary pathogen causing littleleaf disease, other factors such as poor soil aeration, low fertility, periodic moisture stress, and other soil-inhabiting microorganisms are also damaging to fine roots (Oak and Tainter 1988). Loblolly pine, although affected by littleleaf disease, is considered less susceptible and was planted to replace shortleaf pine on sites within the historic range of littleleaf disease (Oak and Tainter 1988, Campbell and Copeland 1954). Littleleaf disease of loblolly pine generally has been reported on eroded Piedmont soils. This is in contrast to the somewhat deeper soil profiles we encountered in our initial soil examinations prior to this study. However, our data suggest decisions to plant loblolly pine on sites with similar characteristics and in similar physiographic areas should be approached with caution, especially if planning rotation ages greater than 35-40 years.

This assessment of loblolly decline included plots in four Physiographic Regions, encompassing a zone in central Alabama from the east (Cleburne and Clay counties) to the west (Tuscaloosa and Hale counties). The evaluation of site variables, including soil classification, bulk density, soil porosity and moisture capacity, and soil nutrient analysis will be a key to assessing the influence of soil and root pathogens recovered from these sites and their relationship to crown characteristics of symptomatic loblolly pines. The soil and site measurements will not be completed until late 2001, at which time a complete evaluation and analysis of all data, including site, root, soil, tree growth, crown indicators, and crown damage will be accomplished. The results of this preliminary study indicate: (1) Management on public lands shows that damage and mortality increases with age of the stands, especially after age 40. (2) Loblolly pine decline symptoms are the same as littleleaf disease of shortleaf pine, and preliminary results of our evaluation show a correlation between reduced radial growth and BA, declining crowns, root damage, and recovery of *P. cinnamomi* and *Leptographium* sp. (3) Loblolly decline is prevalent on sites within the historic range of littleleaf disease and is associated with sites and soils other than the heavy clay soils of the Piedmont Province.

Evaluation of loblolly pine decline in central Alabama is ongoing. The goal is to define the parameters of decline sites, develop a predictive risk model, and estimate amount of land affected. The evaluation of edaphic factors is continuing with soil classification, bulk density analyses, and soil porosity analyses in progress. Soil sample collections for nutrient analysis are scheduled for the summer of 2001. These soil variables will then be incorporated into an overall analysis linking management regimes, root pathological assessments, and root feeding insects, which will further define biological foundations of FHM protocols.

ACKNOWLEDGMENTS

We express appreciation to Gulf States Paper Corporation for providing study sites and specific recognition to Sam Hopkins, Bruce DeHaan, and Mike Allen for their interest and assistance with the project. Thanks to Jim Hyland, Alabama Forestry Commission, and Dale Starkey, Forest Health Protection, for providing training, testing, and oversight of FHM standards and plot establishment. Assistance from Shoal Creek and Oakmulgee Ranger District personnel was very helpful and appreciated for their knowledge and coordination of National Forest stand conditions and sites. Thanks to Art Goddard for assisting with soil classification, and to Kier Klepzig, SRS Pineville, for review and guidance of root-feeding insect collections and associated fungi. The authors also recognize and thank the crews that assisted with field and laboratory work; ie, technical and professional staff from Pineville Field Office (FHP), Tree Root Biology Unit of SRS, and the technical and professional staff of the LSU Plant Pathology Department.

LITERATURE CITED

Allen, L.H. 1994. Letter to Gulf States Paper Corp. from North Carolina State University, Raleigh. NCSFNC. 2 p.

Brown, H.D.; McDowell, W.E. 1968. Status of loblolly pine die-off on the Oakmulgee District, Talladega National Forest, Alabama. Rep. 69-2-28. Pineville, LA: U.S. Department of Agriculture, Forest Service, Forest Insect and Disease Management Group. 21 p.

Campbell, W.A.; Copeland, O.L., Jr. 1954. Littleleaf disease on shortleaf and loblolly pines. Circ. 940. Washington, DC: U.S. Department of Agriculture. 41 p.

Dunn, P.H. 1999. Forest Health Monitoring field methods guide USDA Forest Service, Washington, DC. National Forest Health Monitoring Program – Research Triangle Park, NC 27709.

Ferguson, A.J.; Jeffers, S.N. 1999. Detecting Multiple Species of *Phytophthora* in Container Mixes from Ornamental Crop Nurseries. Plant Disease. 83: 1129-1136.

Haas, W. 1980. Fifty diagnostic special stains for surgical pathology. Los Angeles: All-Type Editorial. 86 p.

Harrington, T.C.; Wingfield, M.J. 1997. Other *Leptographium* species associated with conifer roots. In: Hansen, E.M.; Lewis, K.J., eds. Compendium on conifer diseases. St. Paul, MN: The American Phytopathological Society. 101 p.

Hess, N.J. 1997. Trip report to Shoal Creek Ranger District and Oakmulgee Ranger District. Forest Health Protection, Alexandria, LA. File code: 3400, November 18, 1997. 3 p.

Hess, N.J.; Otrosina, W.J.; Jones, J.P.; Goddard, A.J.; Walkinshaw, C.H. 1999. Reassessment of loblolly pine decline on the Oakmulgee District, Talladega National Forest, Alabama. In: Haywood, J.D., ed. Proceedings of the Tenth biennial southern silvicultural research conference; 1999 February 16-18, Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 560-564.

Hicks, B.R.; Cobb, F.W. Jr.; Gersper, P.L. 1980. Isolation of *Ceratocystis wageneri* from forest soil with selective medium. Phytopathology. 70: 880-883.

Horobin, R.W.; Bancroft, J.D. 1998. Troubleshooting histology stains. Churchill Livingstone, New York. 266 pp.

Jeffers, S.N. 2000. Species of *Phytophthora* and *Pythium*: Pathogens of Trees and Shrubs. Clemson, SC: Clemson University.

Johnson, S.R. 1947. Timber management plan, Cahaba Working Circle, Talladega National Forest, Alabama. R-8 period 7-1-46 to 6-30-56. Intern. Doc. Montgomery, AL: U.S. Department of Agriculture, Forest Service, National Forests in Alabama. 16 p.

Klepzig, K.D.; Raffa, K.F.; Smalley, E.B. 1991. Association of an insect-fungal complex with red pine decline in Wisconsin. Forest Science. 37: 1119-1139.

Lorio, P.L. 1966. *Phytophthora cinnamomi* and *Pythium* species associated with loblolly pine decline in Louisiana. Plant Disease. 50: 596-597.

Oak, S.W.; Tainter, F.H. 1988. Risk prediction of loblolly pine decline on littleleaf sites in South Carolina. Plant Disease. 72: 289-293.

Oak, S.W.; Tainter, F.H. 1988. How to identify and control liffleleaf disease. USDA Forest Service. R8-PR 12.

Otrosina, W.J.; Hess, N.J.; Zarnoch., S.J.; Perry, T.J.; Jones, J.P. 1997. Blue-stain fungi associated with roots of southern pine trees attacked by the southern pine beetle, *Dendroctonus frontalis*. Plant Disease. 8: 942-945.

Roth, E.R. 1954. Spread and intensification of the littleleaf disease of pine. Journal of Forestry. 52: 592-596.

Sass, J.E. 1951. Botanical microtechniques. 2nd ed. Ames, IA: Iowa State College Press. 228 p.

Steinman, J.R.; Hoffard, W.H.; Starkey, D.A. 2000. Forest Health Monitoring in the Southern Region. USDA Forest Service, Southern Research Station (in preparation).

Tainter, F.H.; Baker, F.A. 1996. Principles of forest pathology. New York. John Wiley. 804 p.

USDA Forest Service. 2000. Field instructions for Southern Forest Inventory and Analysis. Southern Research Station, version 04, Asheville, NC.

Walkinshaw, C.H.; Otrosina, W.J.; Hess, N.J. 2001. [In Press]. The importance of histopathology in conifer diseases when Koch's postulates cannot be fulfilled. Phytopathology. 91.

Walkinshaw, C.H.; Tiarks, A.E. 1997. Effects of soil compaction and organic matter removal on morphology of secondary roots of loblolly pine. In: Waldrop, T.A., ed. Proceedings of the Ninth biennial southern silvicultural research conference; 1997 February 25-27, Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 418-421.

COTTONWOOD FIBER FARM PEST MANAGEMENT: COTTONWOOD LEAF BEETLE

T. Evan Nebeker, Michael D. Warriner, and Elwood R. Hart[1]

Abstract—Defoliation by the cottonwood leaf beetle, CLB, (*Chrysomela scripta* F.) can pose a significant threat to the growth and development of one and two-year old Populus plantings. In the southeastern United States, guidelines for monitoring CLB populations at the landscape level have not been fully developed. Accurate determination of when CLB are present in the field could greatly aid in the efficient management of this pest. To address this situation, we compiled data regarding the developmental rate of the CLB to test predictive models of CLB development. Based upon comparisons with field observations, current temperature-dependent growth models hold promise for predicting the occurrence of first generation adult CLB in the field. Prediction of the appearance of specific CLB life stages, especially in subsequent generations, may be somewhat more difficult and requires more examination.

INTRODUCTION

The cottonwood leaf beetle, CLB, (*Chrysomela scripta* F.) is one of the most important economic pests of *Populus* in the United States (Burkot and Benjamin 1979; Drooz 1985). The CLB is a defoliator, with larval and adult stages feeding on the young leaves and shoots of *Populus* clones (Harrell and others 1982). The defoliation that results from CLB feeding activity poses the most threat to one and two-year old plantings, potentially hampering growth and the accumulation of biomass (Calbeck and others 1987; Fang and Hart 2000; Reichenbacker and others 1996). Accurate determination of when CLB are present in the field could greatly aid in the efficient management of this defoliator.

Cottonwood leaf beetles overwinter as adults in leaf litter and under bark, emerging as temperatures rise in the spring (Head 1972). Shortly after emerging, adults mate and females begin to oviposit on the leaves of *Populus* and other suitable hosts. As for most insects, emergence and development of these offspring from egg to adult is closely tied to temperature. To correctly predict emergence dates or developmental time as a function of temperature, the time scale should be represented as physiological time. This physiological time scale is a combination of calendar time and temperature (Mizell and Nebeker 1978). Theoretically, the rate at which heat is accumulated during the spring will determine when specific life stages are expected to be present. Prediction of when CLB adults are apt to first appear in the field would be of benefit to growers in implementing various management tactics.

Insects are known to require a certain amount of heat to develop from one stage to the next (Gilbert and Raworth 1996). This heat requirement is constant and therefore can be used to predict the occurrence of life stages (larvae, pupae, adults) in the field. Temperature-dependent growth models are predictive tools constructed from developmental studies conducted on specific insect species at a series of constant temperatures. A number of such models have been constructed for a variety of insect pests (Davis and others 1996; Fatzinger and Dixon 1996; Pitcairn and others 1992; Raffa and others 1992).

These predictive models of insect development are based upon estimates of heat required by a particular insect species to develop from one stage of its life cycle to the next. For most insects, development generally only occurs within a species-specific, physiologically set range of temperatures. Temperatures above and below this range represent upper and lower developmental thresholds and constitute temperatures at which development slows or ceases. Between these thresholds, the total amount of heat required by an insect to develop from one stage to the next is expressed in degree-days (DD). Degree-days represent the accumulation of temperature over time and are typically calculated above the lower developmental threshold. With knowledge of how many DD are required for the completion of a particular life stage, predictions can be made as to when that stage would be expected to be present in the field.

At present, there is no generally accepted method of determining when CLB adults will first appear in the field. Nor have models been validated to predict when subsequent life stages and generations will be present in the field. The objectives of this study were 1) to compile existing information regarding estimated developmental thresholds and DD requirements for the CLB and 2) to determine the validity of these estimates in the field as predictors of CLB presence and activity.

[1]Professor and Research Associate II, Department of Entomology and Plant Pathology, Mississippi State University, Mississippi State, MS 39762-9775; Professor, Department of Entomology, Iowa State University, Ames, IA 50011-3222, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1— Lower developmental thresholds and degree-day estimates for the cottonwood leaf beetle (*Chrysomela scripta*) compiled from various sources

Source	Lower developmental threshold	Degree-day estimate (egg – adult)
Burkot and Benjamin (1979)- Wisconsin	10.8 °C	257 ± 26.0
Jarrard and others (Unpubl.)- Iowa	8.6 °C	282 ± 16.9
Pope and Nebeker (Unpubl.)- Mississippi	11.8 °C	281 ± 12.2

METHODS

Information regarding the developmental rate of the CLB was obtained from three independently conducted studies (table 1). All three studies examined the effects of a series of constant temperatures on the developmental rate of laboratory-reared CLB. Each study yielded slightly different lower developmental thresholds (LDT) and DD estimates for total preimaginal development. Two of the studies also determined DD requirements for completion of specific CLB life stages (table 2).

Study Site and Insect Sampling

Evaluation of the validity of these DD estimates in the field was conducted during 1999 at a three-year old cottonwood plantation within the Fitler Managed Forest (Crown Vantage) in west central Mississippi (Issaquena County). Cottonwood leaf beetles were monitored using modified boll weevil traps and visual observations. Basic trap layout consisted of eight trap lines spaced approximately 150 meters apart. Each trap line consisted of five traps along with one control point. Each trap was attached to the top of a 3 meter PVC pole. The control point consisted of a PVC pole without a trap. A control point was added to determine if the presence of a trap resulted in increased CLB damage to surrounding trees. Trap lines were installed 25 meters into the plantation and placed between rows of trees. The traps and control point for each trap line were randomly placed 10 meters apart within a line extending into the plantation. Trap lines at both sites were established on March 5, 1999. Traps were checked for adult CLB and trees along each transect were examined for CLB life stages on a weekly basis. Trap catches at all sites were standardized to number of CLB/trap/day. Monitoring for the CLB ceased by early November 1999.

Table 2— Comparison of degree-day estimates for specific cottonwood leaf beetle (*Chrysomela scripta*) life stages

	Degree-day estimate		
Stage	Fitler, MS	Pope and Nebeker	Jarrard and others
Egg	101	74	62
Larvae	79	127	174
Pupae	100	80	46

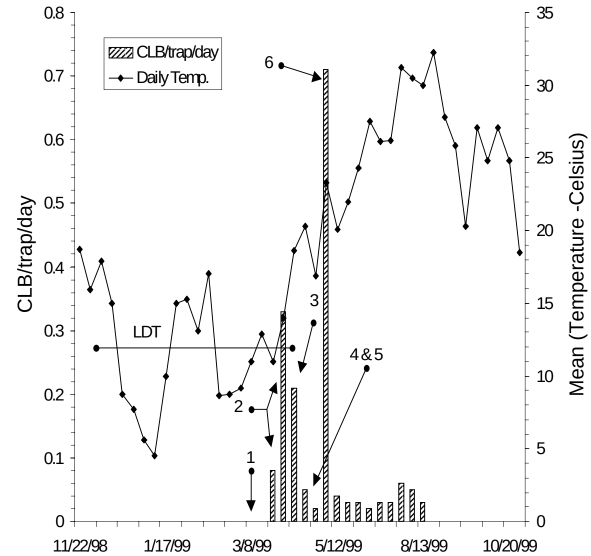


Figure 1—Number of cottonwood leaf beetle adults trapped in relation to average daily temperature: 1) overwintering adults active and present, 2) copulating adults and egg masses present (3/25/99 - 0 DD), 3) CLB larvae present in large numbers, 4) most larvae in pupation at this time, 5) pupal stage continues, and 6) first generation adults eclose in large numbers (4/29/99 - egg to eclosion 280 DD).

Calculation of Degree-days

Accumulation of DD for this CLB population began with first observation of CLB egg masses on the trees (0 degree-days). Daily maximum and minimum temperatures for this site were obtained from the National Climatic Data Center. The closest reporting station to Fitler was in Vicksburg, MS (Warren County) approximately 48 kilometers away. Daily temperatures and DD were calculated in Celsius. We used the LDT of 11.8ºC developed by Pope and Nebeker (unpubl.) to calculate DD for this CLB population. This estimate was appropriate for our validation efforts as Pope and Nebeker (unpubl.) collected CLB from this location to establish their colony at Mississippi State University. The following formula was used to calculate DD:

$$DD = [(m^1 + m^2)/2] – t$$

Where DD represents the degree-days accumulated over a 24 hour period, m^1 the maximum temperature over the 24 hour period, m^2 is the minimum temperature for that 24 hour period above the LDT, and t the LDT for the species in question (Pedigo and Zeiss 1996).

RESULTS AND DISCUSSION

Over the spring and summer of 1999 we observed the emergence of overwintered adults, copulation, oviposition of eggs, larval feeding, pupation, and eclosion of first generation adults. Figure 1 depicts trap catches of CLB adults in relation to average daily temperature. It is evident from this graph that no adult CLB were trapped until average daily temperatures rose above the LDT of 11.8ºC.

Adults emerging from their overwintering sites were first trapped March 18, 1999 after an accumulation of 136 DD with DD accumulation beginning Dec. 1, 1998. Numbers of adult CLB trapped increased a few weeks later (March 25, 1999). This increase roughly coincided with observations of large numbers of copulating pairs and ovipositing females. Numbers of adult CLB trapped and observed on trees declined after that date. As overwintering adults passed away and trap numbers declined, first generation offspring passed through their various life stages. Numbers of adults trapped reached their highest level on April 29, 1999 coinciding with the eclosion of first generation adults.

Twenty-six DD were calculated (figure 1) from a start date of March 25, 1999 as that date marked the first observation of large numbers of CLB egg masses. Accumulation of DD ceased on April 29, 1999 coinciding with eclosion of first generation adults. Based on our observations, this CLB population required approximately 280 DD to complete development (egg – adult). From eggs to larvae 101 DD, from larvae to pupae 79 DD and from pupae to new adults 100 DD (figure 1).

Degree-days required to complete each life stage (egg, larvae, pupae, adult) were also calculated and compared to those of Pope and Nebeker (unpubl.) and Jarrard and others (unpubl.). Whereas total number of estimated DD required for complete development are similar, there is somewhat more variation among the various life stages (table 2).

Our field estimate for complete CLB development corresponds almost perfectly with the predicted estimates of Pope and Nebeker (unpubl.) and Jarrard and others (unpubl.). Both estimates, 281 DD and 282 DD, respectively, occurring just one calendar day past ours. The minimum predicted estimate derived by Burkot and Benjamin (1979) of 257 DD was reached two calendar days prior to our field estimate. The estimate of 280 DD we obtained best coincides with an observed peak in first generation eclosion. Since our observations were only conducted weekly it is very likely that first generation CLB were eclosing prior to 280 DD. Although promising, additional efforts need to be put toward validating these models in the field before reliable predictions can be made.

SUMMARY

Based on this limited data, current temperature-dependent growth models hold promise for predicting the occurrence of first generation adult CLB in the field. However, predicting the appearance of specific life stages may be more difficult as evidenced by the variability in degree-day requirements we observed among our own, and others, estimates.

ACKNOWLEDGMENTS

We appreciate the assistance of Jeff Portwood of Crown Vantage and Billy VanDevener of Van Development Corporation for allowing us access to the plantation and encouraging the work on the cottonwood leaf beetle. We also acknowledge the monetary support and guidance of International Paper and Westvaco through Scott Cameron and Randy Rousseau respectively to the *Populus* Pest Management Research Program at Mississippi State University and Iowa State University. We also acknowledge William Jones for assistance in data collection and analysis.

REFERENCES

Burkot, T.R.; D.M. Benjamin. 1979. The biology and ecology of the cottonwood leaf beetle, *Chrysomela scripta* (Coleoptera: Chrysomelidae), on tissue cultured hybrid *aigeiros* (Populus x Euramericana) subclones in Wisconsin. Canadian Entomology. 111: 551-556.

Caldbeck, E.S.; H.S. McNabb; E.R. Hart. 1987. Poplar clonal preferences of the cottonwood leaf beetle. Journal of Econonomic Entomology. 71: 518-520.

Davis, P.M.; N. Brenes; L.L. Allee. 1996. Temperature dependent models to predict regional differences in corn rootworm (Coleoptera: Chrysomelidae) phenology. Environmental Entomology. 25(4): 767-775.

Drooz, A.T. 1985. Eastern forest insects. USDA Forest Service Miscellaneous Publication 1426. Washington, D.C.

Fang, Y.; E.R. Hart. 2000. Effect of cottonwood leaf beetle (Coleoptera: Chrysomelidae) larval population levels on *Populus* terminal damage. Environmental Entomology. 29(1): 43-48.

Fatzinger, C.W.; W.N. Dixon. 1996. Degree-day models for predicting levels of attack by slash pine flower thrips (Thysanoptera: Phlaeothripidae) and the phenology of female strobilus development on slash pine. Environmental Entomology. 25(4): 727-735.

Gilbert, N.; D.A. Raworth. 1996. Insects and temperature: a general theory. Canadian Entomology. 128(1): 1-14.

Harrell, M.O.; D.M. Benjamin; J.G. Berbee; T.R. Burkot 1982. Consumption and utilization of leaf tissue of tissue cultured *Populus x Euramericana* by the cottonwood leaf beetle, *Chrysomela scripta* (Coleoptera: Chrysomelidae). Canadian Entomology 114(8): 743-749.

Head, R.B. 1972. Studies on the cottonwood leaf beetle, *Chrysomela scripta* (Fab.) with emphasis on reproductive potential, biology, parasites, predators, insecticide resistance, and esterase comparisons. Mississippi State, MS: Mississippi State University. Ph.D Disseratation.

Mizell, R.F.; T.E. Nebeker 1978. Estimating the developmental time of the southern pine beetle, *Dendroctonus frontalis* as a function of field temperature. Environmental Entomology. 7: 592-595.

Pedigo, L.P.; M.R. Zeiss. 1996. Analyses in insect ecology and management. Ames, IW: Iowa State University Press.

Pitcairn, M.J.; F.G. Zalom; R.E. Rice. 1992. Degree-day forecasting of generation time of *Cydia pomonella* (Lepidoptera: Tortricidae) populations in California. 21(3): 441-446.

Raffa, K.F.; D.J. Hall; W. Kearby; S. Katovich. 1992. Seasonal life history of introduced basswood thrips (Thysanoptera: Thripidae) in Wisconsin, with observations on associated thrips species. Environmental Entomology. 21(4): 771-779.

Reichenbacker, R.R.; R.C. Schultz; E.R. Hart. 1996. Impact of artificial defoliation of *Populus* growth, biomass production, and total non-structural carbohydrate concentration. Environmental Entomology. 25: 632-642.

THE EFFECTS OF THINNING ON BEETLES (COLEOPTERA: CARABIDAE, CERAMBYCIDAE) IN BOTTOMLAND HARDWOOD FORESTS

Michael D. Warriner, T. Evan Nebeker, Theodor D. Leininger, and James S. Meadows[1]

Abstract— The responses of two groups of beetles, ground beetles (Carabidae) and longhorned beetles (Cerambycidae), to a partial cutting technique (thinning) applied to major and minor stream bottom sites in Mississippi were examined. Species diversity of ground beetles and longhorned beetles was greater in thinned stands than unthinned stands two years following thinning. Higher diversity of ground beetles in thinned stands was primarily attributable to the presence of species that prefer open, disturbed conditions. Longhorned beetles that use dead wood as larval host material dominated collections in thinned stands. Although the two beetle groups examined seemed to favor certain habitat conditions brought about by thinning, how other invertebrates (litter fauna, herbivores) respond will require additional investigation.

INTRODUCTION

Terrestrial insects represent an integral component of bottomland hardwood forests yet they have rarely been considered in light of their response to forest management. Insects are known to play a number of important roles (pollination, nutrient cycling, predation) in forest systems and represent a vital food source for other organisms (Janzen 1987; Packham and others. 1992). Although little studied in these settings, insects have the potential to provide a great deal of information regarding bottomland hardwood forests. However, an obstacle confronting many insect-related projects is the overwhelming diversity of species that can be collected (Disney 1986).

As an alternative to sampling all insects, assemblages of select species representing different ecological or functional roles have been suggested for use as monitoring tools or indicators of environmental change (Kremen and others 1993). Beetles (Coleoptera) are considered well suited for such purposes as they display a wide range of functional roles (herbivores, predators, fungivores), are easily sampled through a variety of passive-trapping methods, and good taxonomic information exists for many families (Hutcheson and Jones 1999).

In bottomland hardwood forests, studies evaluating beetles as indicators of environmental change are rare. Most studies conducted thus far have taken the form of faunal surveys (Allen and Thompson 1977; Goff 1952; Grey 1973; Shelford 1954) or examined the influence of natural disturbances on beetles and other terrestrial arthropods (Gorham and others 1996; Uetz and others 1979). In one of the few examples, Thompson and Allen (1993) investigated the response of ground beetles (Carabidae) to different site preparation techniques applied to a clearcut bottomland hardwood stand. In their study, they identified ground beetle species considered to be indicative of disturbed conditions in bottomland hardwood forests.

The objective of this study was to investigate the impact of the partial cutting technique, thinning, on species diversity and abundance of two beetle families in bottomland hardwood forests. Ground beetles were included as one of the target taxa. Ground beetles have generally been regarded as a good group through which to evaluate habitat change (Gardner 1991; Niemelä and others 1993; Thiele 1977). The majority of ground beetle species are predaceous feeding on other invertebrates. Through patterns in their diversity and abundance, ground beetles can provide indirect information regarding the status of their prey and how alterations in habitat conditions affect them (Day and Carthy 1988).

To gauge the impact of thinning from another ecological perspective, longhorned beetles (Cerambycidae) were selected as the second target group. Most longhorned beetle species are xylophagous, feeding on trees, shrubs, and woody vines. While some longhorned beetles feed on healthy woody plants, most species feed on dying or dead woody material, playing important roles in the fragmentation and breakdown of dead wood (Fellin 1980). Due to their dependence upon dead wood, longhorned beetles have the potential to serve as potentially sensitive indicators of forest conditions (Yanega 1996). Evaluation of how both of these groups of beetles respond to the thinning process should provide insight into how their respective habitats are effected, and what that might portend for other members of the bottomland fauna.

[1]Research Associate II and Professor, Department of Entomology and Plant Pathology, Mississippi State University, Mississippi State, MS 39762-9775; Principal Research Plant Pathologist and Principal Silviculturist, USDA Forest Service, Southern Research Station, Stoneville, MS 38776-0227; respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

METHODS

Study Site

This study was conducted in bottomland hardwood stands within major and minor stream bottom sites in Mississippi. The major stream bottom site was located in the Delta National Forest (Sharkey County) in west-central Mississippi. Dominant tree species included sweetgum (*Liquidambar styraciflua*), willow oak (*Quercus phellos*), Nuttall oak (*Q. nuttallii*), sugarberry (*Celtis laevigata*), and various elms (*Ulmus* spp.). Treatments at this site consisted of a commercial thinning applied in 1997 and an unthinned control. The minor stream bottom site was located on private land in Monroe County in northeastern Mississippi. Dominant tree species consisted of willow oak (*Q. phellos*), sweetgum (*L. styraciflua*), and elms (*Ulmus* spp.) Treatments applied at the minor stream bottom site also consisted of a commercially thinning applied in 1997 and an unthinned control. Thinnings applied at both sites removed poorly formed, diseased, and otherwise unmerchantable tree species and favored well-formed sweetgum and oaks to improve quality of the residual stand.

Beetle Sampling

Sampling for ground beetles and longhorned beetles was conducted in 1999, two years post-thinning. Ground beetles were sampled using pitfall traps. Twelve pitfall traps were placed along transects in each thinned and unthinned stand. Individual pitfall traps were placed 10 meters apart and consisted of two 1.8 liter plastic containers. One container was sunk flush with the ground as a liner and the second container placed into it. Traps were filled with 4-6 centimeters of propylene glycol as a preservative and killing agent. A number of holes were punched in the bottom of the second plastic container to serve as a sieve for removal of insects from traps. A 0.1 meter2 wooden roof supported by nails was placed over each pitfall trap to prevent flooding by rainwater. Traps were operated continuously from April to October 1999. Captured ground beetles were removed from pitfall traps every two weeks and stored in vials containing 70 percent ethanol. All collected specimens were identified to species.

Longhorned beetles were sampled using Malaise traps and barrier traps (flight-intercept traps). Malaise traps are large tent-like structures that passively trap low-flying insects and collect them in a container filled with a preservative/killing agent (Townes 1972). Collecting containers were filled with 70 percent ethanol. One Malaise trap was placed in each thinned and unthinned stand. Traps were oriented in a north-south direction with collecting heads facing south.

Barrier traps, modified from Økland (1996), consisted of two perpendicular clear plastic sheets (35 centimeters x 40 centimeters) attached to a collecting container (33 centimeters in diameter). Collecting containers were filled with 3-5 centimeters of propylene glycol. A clear plastic roof was placed on top of the intersecting sheets to prevent rainfall from entering the collecting container. Individual traps were hung between two trees at a height of approximately 1.5 meters. Five barrier traps were placed in each thinned and unthinned stand with 10 meters between individual traps. Malaise and barrier traps were operated continuously from April to October 1999. Insects from both trap types were collected every two weeks. Longhorned beetles were removed from trap catches, stored in 70 percent ethanol, and identified to species.

To evaluate longhorned beetle activity in thinned and unthinned stands, we determined the larval host preferences of collected species. Species were assigned to one of four host groups; 1) healthy hosts – species feeding on healthy woody plants, 2) weakened/stressed hosts – species feeding on woody plants weakened by disease, injuries, or other causes, 3) dead/decaying hosts – species feeding on downed or standing dead trees and branches in various stages of decay, and 4) unknown hosts – species for which larval host preference is unknown. Host preferences were compiled from Craighead (1923), Hanula (1996), Solomon (1995), and Yanega (1996).

Statistical Analyses

Species diversity of ground beetles and longhorned beetles was evaluated using rarefaction (Simberloff 1972). Rarefaction estimates the number of species in a random subsample to the entire sample. The resulting value can then be interpreted as a measure of diversity because the technique takes into account both species richness and abundance. Numbers of individuals were compared among treatments and study sites using analysis of variance (ANOVA). For longhorned beetles, distribution of numbers of individuals representing each functional group was compared between thinned and unthinned stands (pooled data) using a Chi-square test.

RESULTS AND DISCUSSION

Ground Beetle Diversity and Abundance

Overall, 13 species of ground beetles were collected from the major stream bottom site. Eight species were collected from the minor stream bottom. Species diversity, as estimated by rarefaction in a sample of 50 individuals, was greater for thinned stands than unthinned stands in both major and minor stream bottoms (figure 1). Higher diversity in the thinned stands is mostly reflective of the presence of a number of ground beetles species typical of open, disturbed habitats. The large, predatory ground beetles *Calosoma scrutator* and *Pasimachus punctulatus*, along with *Harpalus pennsylvanisus* were only collected from thinned stands. *Calosoma scrutator* is a species generally found in open hardwood forests, while *P. punctulatus* and *H. pennsylvannicus* are species typical of open, grassy fields.

Thompson and Allen (1993) suggest that finding ground beetles species such as these in bottomland hardwood forests is indicative of disturbance. Presence of these species suggests that the thinning operation did alter habitat conditions in these stands. With the removal of large number of trees, thinned stands are more open than unthinned stands, possessing a sparse understorey. As a result, more sunlight reaches the forest floor, leading to somewhat drier conditions and promoting increased growth of grasses and herbaceous vegetation. There are a number of published examples where disturbances created by silvicultural practices increases ground beetle species diversity by increasing habitat complexity (Beaudry and others 1997; Niemelä and others 1988; Parry and Rodger 1986). In those cases, as well as here, much of that increase is attributable to the colonization or increased activity of species characteristic of open, dry conditions.

However, thinning operations did not appear to effect habitat conditions so severely that species from unthinned stands were restricted from thinned stands. *Brachinus alternans* is a species common in closed-canopy bottomland hardwood forests and has been considered to be indicative of undisturbed stands (Thompson and Allen 1993). This species was the most commonly collected ground beetle at all sites and was present in larger numbers in thinned stands. In addition, total ground beetle abundance did not differ significantly between thinned and unthinned stands ($F = 1.426$; d.f. = 1,24; $P = 0.2440$). Based on this, the supposition can be made that the thinnings conducted two years prior did not negatively impact populations of the ground beetle species examined.

Longhorned beetle Diversity and Abundance

A total of 17 species of longhorned beetle were collected from the major stream bottom site, while 23 species were collected from the minor stream bottom. Species diversity, as estimated by rarefaction in a sample of 50 individuals, was greater for thinned stands than unthinned stands in both major and minor stream bottoms (figure 2). Unlike ground beetles, abundances of longhorned beetles were significantly higher in the thinned stands ($F = 4.757$; d.f. = 1,46; $P = 0.0343$) than unthinned stands.

All longhorned beetle species collected at both sites feed on woody plant tissue as larvae. When compared to unthinned stands, thinned stands contained significantly higher numbers ($\chi^2 = 26.803$; d.f. = 2; $P = <0.0001$) of species that feed on dead/decaying wood and weakened/dying woody plants (figure 3). Thinned stands also contained fewer numbers of species that feed on healthy hosts. The most commonly trapped longhorned beetle in both thinned and unthinned stands was *Elaphidion mucronatum*. *Elaphidion mucronatum* feeds on the dead branches of a variety of hardwood species and was collected more frequently in thinned stands. Other dead wood feeders present in higher numbers in the thinned stands included *Typocerus zebra*, *Stenosphenus notatus*, *Doraschema cinereum*, and *Enaphalodes atomarius*. Thinning operations at both major and minor stream bottom sites left behind large amounts of logging slash in the form of branches and harvest tops. Such material represents suitable host material for these species, as well as other beetles (Buprestids, Scolytids, Platypodids) that rely on dead wood as food or habitat.

The most commonly collected species feeding on weakened/dying hosts were *Neoclytus acuminatus* and *Xylotrechus colonus*. *Neoclytus acuminatus* feeds on the sapwood of weakened, dying, and recently dead hardwood trees, while *X. colonus* feeds on phloem of a number of hardwood tree species. These species were also collected in unthinned stands but in lower numbers. Higher abundances of these beetles in thinned stands again most likely reflects input of dying and dead woody material from the thinning operation. Higher abundances of these species may also be attributable to damages to the residual stand resulting from logging wounds.

During thinning operations, damage to the residual stand may result. Wounding to the residual trees generally occurs when a harvested tree falls into a residual tree, or when logging equipment causes damage to the residual stems. At the major stream bottom site, logging wounds were especially high in the thinned stand, with 84 percent of the

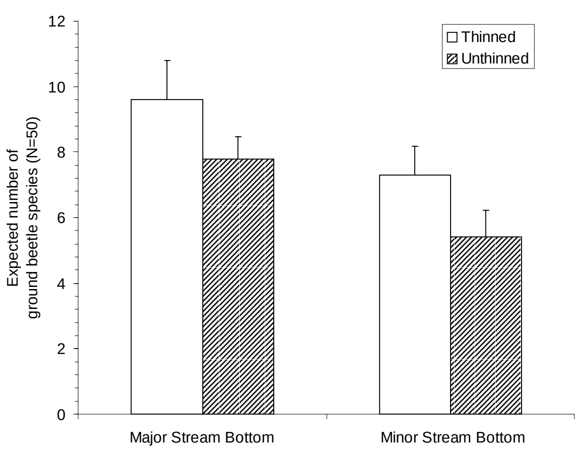


Figure 1—Ground beetle species richness, as estimated by rarefaction, in thinned and unthinned stands at major and minor stream bottom sites in Mississippi.

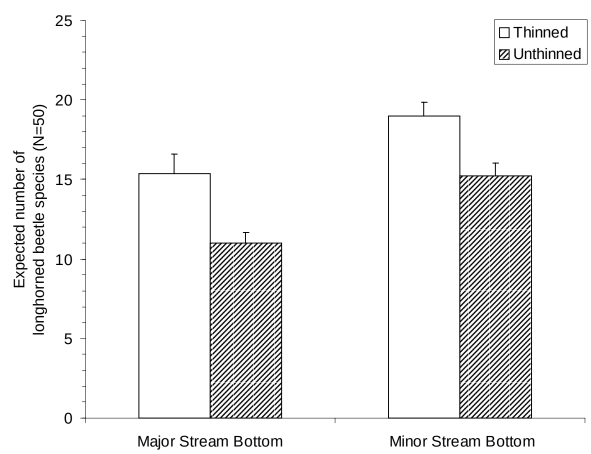


Figure 2—Longhorned beetle species richness, as estimated by rarefaction, in thinned and unthinned stands at major and minor stream bottom sites in Mississippi.

residual stems damaged in some way (Nebeker and others 1999). Wounds to the bole, roots, and branches can provide places for insects to enter and serve as infection courts for pathogens. Post-thinning surveys at this site have since shown that borer wounds have increased in the thinned stand, with many of these occurring on logging wounds (Nebeker and others 1999). In the case of insects, wounded trees are known to release volatile compounds that attract certain wood-boring beetles (Dunn and others 1986). Reduction of logging wounds might be expected to have a concomitant effect on reducing wood-boring beetle activity.

Longhorned beetle species feeding on healthy hosts were few in number. All species collected were twig pruners and borers, such as *Anelaphus parallelus*, *Oberea tripunctata*, and *Psyrassa unicolor*. These species were present in similar numbers in thinned and unthinned stands.

CONCLUSIONS

Both groups of beetles exhibited some response to thinning. Certain ground beetles responded to habitat changes brought about by the thinning process (open, disturbed conditions), whereas longhorned beetles responded to the input of dying and dead wood in the form of logging slash. Intermediate levels of disturbance are thought to enhance species diversity by increasing habitat structural complexity (Connell 1978). In the case of both of these beetle families, species diversity and abundance were increased to some degree. Increased diversity and abundance of these insects could be expected to have ramifications for other faunal groups. Other invertebrates that prefer open, disturbed conditions would also be expected to increase in thinned stands, along with species that use dead wood as habitat or a food source. In addition, those insect species that take advantage of weakened or wounded trees clearly benefit if logging damage to the residual stand is great. With increases in certain insect populations, predators (birds, reptiles) of these groups might also be expected to increase their foraging activity in thinned stands.

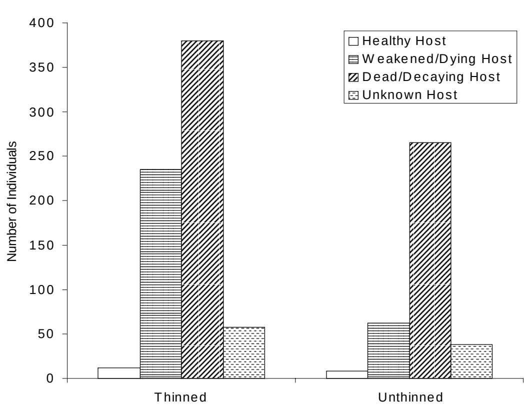


Figure 3—Larval host preferences of longhorned beetles collected in thinned and unthinned stands (pooled data) at major and minor stream bottom sites in Mississippi.

However, how long certain groups can maintain higher abundances is uncertain. Although longhorned beetles were present in higher numbers in the thinned stand, presumably due to the increased amount of host material (dead wood). The majority of dead wood left behind by the thinning operation was not large diameter material, rather it was smaller diameter branches. This material will eventually decay and reach stages where it is no longer useful to many of the longhorned beetles we collected. The thinning operation was designed to improve the quality of the residual stand and therefore diseased and undesirable trees were removed leaving a healthier stand. Those trees that were removed were trees that could have contributed to dead wood volume in the future. Consequently, dead wood input might be expected to be lower in thinned stands than unthinned stands over time. If that is true then longhorned beetle numbers in thinned stands may reach numbers comparable to or lower than unthinned stands.

ACKNOWLEDGMENTS

We are grateful for the cooperation of Larry Moore, District Ranger and Ralph Pearce, Timber Officer of the Delta National Forest in establishing plots and facilitating the thinning. Appreciation is also extended to John Hart for access to the site in northeastern Mississippi. William D. Jones provided a great deal of assistance in collection and processing of insect samples. The contributions of Terry Schiefer of the Mississippi Entomological Museum at Mississippi State University in beetle identification were invaluable. This project was funded in part by the Mississippi Agricultural and Forestry Experiment Station and the U.S. Forest Service, Southern Research Station, Center for Bottomland Hardwoods Research, Southern Hardwoods Laboratory through cooperative agreement no. SRS30-CA-96-061.

REFERENCES

Allen, R.T.; R.G. Thompson. 1977. Faunal composition and seasonal activity of Carabidae (Insecta: Coleoptera) in three different woodland communities in Arkansas. Annals Entomology Society of America. 70(1): 31-34.

Beaudry, S.; L.C. Duchesne; B. Côté. 1997. Short-term effects of three forestry practices on carabid assemblages in a jack pine forest. Canadian Journal of Forest Research. 27: 2065-2071.

Connell, J.H. 1978. Diversity in tropical rainforests and coral reefs. Science. 199: 1302-1310 .

Craighead, F.C. 1923. North American cerambycid larvae. Candada Deptartment of Agriculture Bulletin. 27 p.

Day, K.R.; J. Carthy. 1988. Changes in carabid beetle communities accompanying a rotation of Sitka spruce. Agricultural Ecosystems and Environment. 24: 407-415 .

Disney, R.H.L. 1986. Inventory surveys of insect faunas: discussion of a particular attempt. Antennae. 10(3): 112-116 .

Dunn, J. P.; T. W. Kimmerer; G. L. Nordin. 1986. Attraction of the twolined chestnut borer,*Agrilus bilineatus* (Weber) (Coleoptera: Buprestidae), and associated borers to volatiles of stressed white oak. Canadian Entomology. 118(6): 503-509.

Fellin, D.G. 1980. A review of some interactions between harvesting, residue management, fire, and forest insects and diseases. In Environmental consequences of timber harvesting in Rocky Mountain coniferous forests, symposium proceedings. General Technical Report INT-90: U.S. Department of Agriculture, Forest Service.

Gardner, S.M. 1991. Ground beetle (Coleoptera: Carabidae) communities on upland heath and their association with heathland flora. Journal of Biogeography. 18: 281-289 .

Goff, C.C. 1952. Floodplain animal communities. American Midland Naturalist. 57(2): 478-486 .

Gorham, L.E.; B.D. Keeland; S. Mopper; S.L. King; D.J. Johnson. 1996. Effects of canopy gap dynamics on arthropod abundance in a bottomland forest in northeast Arkansas. In: Flynn, K.M., ed. Proceedings of the Southern Forested Wetlands Ecology and Management Conference. Consortium for Research on Southern Forested Wetlands, Clemson University: Clemson, SC.

Grey, W.F. 1973. An analysis of forest invertebrate populations of the Santee-Cooper Swamp, a floodplain habitat. Columbia, SC: University of South Carolina. M.S. Thesis

Hanula, J.L. 1996. Relationship of wood-feeding insects and coarse woody debris. In: McMinn, J.W. and D.A. Crossley, Jr. eds. Biodiversity and coarse woody debris in southern forests, proceedings of the workshop on coarse woody debris in southern forests: effects on biodiversity; 1993 October 18-20; Athens, GA. Gen. Tech. Rep. SE-94 Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 55-81.

Hutcheson, J.; D. Jones. 1999. Spatial variability of insect communities in a homogeneous system: measuring biodiversity using Malaise trapped beetles in a *Pinus radiata* plantation in New Zealand. Forest Ecology Management. 118: 93-105.

Janzen, D.H. 1987. Insect diversity of a Costa Rican dry forest: why keep it and how. Biological Journal. Linn. Soc. 30: 343-356.

Kremen, C.; R.K. Colwell; T.L. Erwin; D.D. Murphy; R.F. Noss; M.A. Sanjayan. 1993. Terrestrial arthropod assemblages: their use in conservation planning. Conservation Biology 7(4): 796-808.

Nebeker, T.E.; T.D. Leininger; J.S. Meadows. 1999. Silvicultural practices in forests of the southeastern United States: insect and disease considerations. In: Haywood, J.D. ed. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16-18; Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 555-559.

Niemelä, J.; D. Langor; J.R. Spence. 1993. Effects of clear-cut harvesting on boreal ground-beetle assemblages (Coleoptera: Carabidae) in western Canada. Conservation Biology. 7(3): 551-560 .

Økland, B. 1996. A comparison of three methods of trapping saproxylic beetles. European Jorunal of Entomology. 93: 195-209 .

Packham, J.R.; D.J.L. Harding; G.M. Hilton; R.A. Stuttard. 1992. Functional ecology of woodlands and forests. London: Chapman Hall.

Parry, W.H.; D. Rodger. 1986. The effect of soil scarification on the ground beetle fauna of a Caledonian pine forest. Scottish Forestry. 40: 1-9 .

Shelford, V.E. 1954. Some lower Mississippi Valley floodplain biotic communities: their age and elevation. Ecology 35(2): 126-142.

Simberloff, D.S. 1972. Properties of the rarefaction diversity measurement. American Nature. 106: 414-418.

Solomon, J.D. 1995. Guide to insect borers of North American broadleaf trees and shrubs. U.S. Forest Service: AH-706.

Thiele, H.U. 1977. Carabid beetles in their environments: a study on habitat adaptation, physiology and behavior. Springer-Verlag, Berlin.

Thompson, L.C.; R.T. Allen. 1993. Site preparation affects ground beetles in a clearcut bottomland hardwood forest in southeastern Arkansas. In: Brissette, J.C., ed. Proceedings of the Seventh biennial southern silvicultural research conference; 1992 November 17-19, Mobile, AL. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 57-64.

Townes, H. 1972. A light-weight malaise trap. Entomology News. 83: 239-247.

Uetz, G.W.; K.L. Van der Laan; G.F. Summers; P.A.; Gibson; L.L. Getz. 1979. The effects of flooding on floodplain arthropod distribution, abundance and community structure. American Midland Naturalist. 101(2): 286-299.

Yanega, D. 1996. Field guide to northeastern longhorned beetles (Coleoptera: Cerambycidae). Natural History Survey Manual. 6.

TIP-DIEBACK IN YOUNG LOBLOLLY PINE PLANTATIONS

David B. South, Patrick Brown, Phillip M. Dougherty, Sonya Olykan, Brett Runion, Adya Singh, and Malcolm Skinner[1]

Abstract— Dieback of loblolly pine (*Pinus taeda* L.) has been observed in certain intensively managed plantations throughout the South. There are two distinct types of dieback; winter dieback usually appears in February and March while summer dieback appears in July (or later) and increases during the fall. Both types have very high levels of K in terminal shoots. Winter dieback progresses in a "top-down" pattern while summer dieback progresses in a "bottom-up" pattern. Winter-dieback appears to be related to freezes and growth rate as slower-growing wildlings in the plantation almost never exhibit dieback. Freeze injury (brown cambium) is sometimes observed in the stem (at breast-height) and in the terminal shoot. Often the terminal pith turns brown. One fast-growing family, 7-56 from the Coastal Plain in South Carolina, is sensitive to freezes and is prone to tip-dieback. Although winter dieback is most noticeable in plantations, it also occurs on open-grown trees that are growing in weedy, non-fertilized areas. Land managers have grown accustomed to this dieback in rapidly growing plantations that are 2 to 5 years old. On some soils, summer dieback appears to be exacerbated after fertilization with macronutrients. There is currently no consensus as to the cause of this phenomenon but we believe that growth rate, freezes, K, and B may be involved. This paper reviews some of the literature on dieback on pines and proposes some hypotheses to test.

INTRODUCTION

For more than 30 years, a disease of unknown etiology has been observed on fast-growing plantations of loblolly pine. The first reported cases were made by Doug Crutchfield at Georgetown, South Carolina (Clark 1972). Terminals of 4-year-old loblolly pine died back and subsequently, one or more lateral branches assumed dominance. It was concluded that the most likely explanation was due to freeze injury. "The trees were young. They were growing at a rapid rate due to good site conditions, hence any fall flush of growth probably would not have hardened-off in time to be protected from early frost."

Dieback ranges from Virginia to Florida and west as far as Louisiana. Many cases involved intensively managed plantations planted with family 7-56. As more cases were investigated, it became apparent that there was no consensus as to the cause of the dieback. The objective of this paper is to review the current state of knowledge and to propose alternative hypotheses to explain this phenomenon.

SYMPTOMS

There are two types of dieback: winter and summer. Winter symptoms appear after several warm days following hard freeze events. Although the freeze event may occur in mid-December or in January, symptoms in Alabama typically begin to appear in late February and March. On some trees, symptoms begin to appear in April. The date of the first appearance of winter symptoms will vary with both year and latitude. There is a "top-down" pattern of symptom progression; necrotic tissue first appears at the top of the shoot. On some trees, the pith of the terminal shoot is necrotic and affected needles are typically entirely necrotic. The terminal shoot of affected trees usually is easy to snap-off, indicating a lack of lignification. Although there are no reports of wide-spread dieback in 10-year-old plantations, open-grown trees that are 10 to 18 years old (or older) have shown signs of winter dieback. Pictures of winter dieback are found at: www.forestry.auburn.edu/south/tipdieback.html.

When new needles develop in April, they appear unaffected. By mid-summer, necrotic needles have fallen off and many stands appear to be growing normally. Upon close examination, some trees show dead terminals with a lateral bud expressing dominance. At some locations, the entire 1 m of the top is dead on a few trees and the crown develops a bushy appearance. Casual observations suggest soil type is not related to the occurrence of winter symptoms.

On some sites, dieback occurs during the summer and fall. Summer-dieback can appear in July and gradually increases over the next several months. These symptoms develop in a "bottom-up" pattern. By September, the 3rd flush may have 50 percent of the needle length affected while needles on the 5th and 6th flush are symptom free (Martin and Blakeslee

[1]Professor, School of Forestry and Wildlife Sciences, Auburn University, AL; Professor, Department of Pomology, UC Davis, Davis, CA; Scientist, Westvaco, Summerville, SC; Scientist, Forest Research, Christchurch, NZ; Plant Pathologist, National Soil Dynamics Laboratory, Auburn, AL; Scientist, Soil Scientist Forest Research, Rotorua, NZ, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Table 1— Seedbed density, mean root-collar diameter (RCD) and visual freeze damage estimates (percent of seedlings) for 60 seedlings from five seedlots at a nursery in Alabama in February 1996. A –9° C freeze occurred on January 19 and a –13° C freeze occurred on February 5

Family	Density	RCD	Damage
	#/m2	mm	%
7-56	237	5.3	97
12-42	215	5.6	27
1-82	237	5.4	15
1.5 orchard mix	215	5.0	22
2.0 orchard mix	226	4.7	13

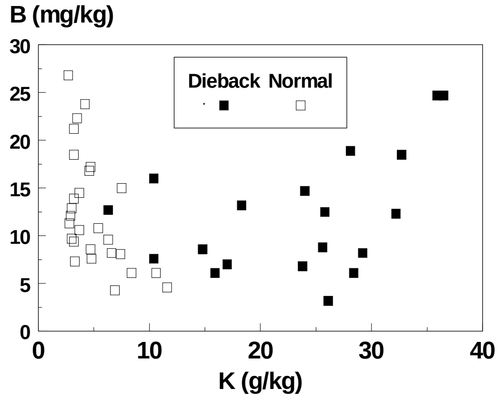


Figure 1— Concentrations of B and K in the foliage of the terminal shoots from normal (open squares) and symptomatic (closed squares) loblolly pines exhibiting winter dieback in Alabama. Each point represents one tree.

1998). By mid-November, the 5th and 6th flush will have affected needles. Necrosis appears on needle tips first and then progresses down the fasicle. On each needle, there is a sharp transition from necrotic tissue to living tissue and the distance from the tip to the transition line is the same on all three needles. On some trees, the terminal buds die and dry out. On a few trees, the terminal growth is deformed and the lateral branches form a "nest-like" appearance (Martin and Blakeslee 1998).

For both winter and summer symptoms, the probability of occurrence in intensively-managed plantations is highest 2 to 5 years after planting and then appears to decline with age. Some shoots with dieback have many 4- and 5-needle fasicles. As trees get older and larger, competition increases and the incidence of dieback decreases.

The symptoms have a genotypic component since fast-growing families are more susceptible than others. In particular, family 7-56 often shows winter dieback symptoms and on certain sites, has exhibited summer dieback symptoms. Wildlings in the same plantation almost never show dieback symptoms. Slash pine (*Pinus elliottii*) does not appear to be affected in intensively managed stands.

SIX HYPOTHESES

Tip-dieback in intensively managed plantations can likely be explained by one of the following hypotheses: 1) freeze injury; 2) K imbalance; 3) B deficiency; 4) some other abiotic agent; 5) a biotic agent. Since there are two types of dieback, it is possible dieback is; 6) caused by two independent factors.

The Freeze Injury Hypothesis

Winter dieback symptoms might be simply explained by freezing temperatures as suggested by Clark (1972) 30 years ago. Low temperatures that cause injury to pines will vary with the amount of warm weather that precedes the freeze (Mexal and others 1979). For example, a –4° C freeze at a nursery can injure loblolly pine needles in November (South and others 1993). In late December or early January, it may require a –7° C freeze. However, if loblolly seedlings are from a northern seed source and are well acclimated (with no succulent tissue), a –16° C freeze in late-December might cause little visual injury to seedlings in a bare-root nursery. The degree of freeze injury will depend on how many cells in the cambium are actively dividing at the time of the freeze. Winter dieback of Corsican pine (Pinus nigra var. calabrica) is more likely to occur when a February freeze of –7° C follows a mild period than when a –14° C freeze follows a cold January (Read 1967).

Some loblolly families can be injured at –5° C (Hodge and Weir 1993) and family 7-56 is susceptible to freeze injury (table 1). Certain individuals within this family are more freeze sensitive than others. On January 26, 1999, the temperature at Auburn, AL dropped to –7° C and symptoms were noticed in two intensively managed 7-56 plantations at the end of February. Further investigations revealed freeze injury symptoms (brown tissue) under the bark at breast height.

One year later, on December 21, 2000, temperatures at Auburn, AL dropped to –10° C and dieback symptoms were noticed on several open-grown trees (ages > 10 years) two months later on February 24, 2001. Three trees were located on the campus of Auburn University. Intensively managed plantations (7-56) also showed symptoms.

At Waycross, GA, temperatures dropped to –7° C (December 21, 1996) and summer dieback symptoms were noticed on an intensively managed plantation (7-56) seven months later in July (Martin and Blakeslee 1998). This plantation was planted in December, 1995 and, therefore, the trees were about 2.5 years old from seed when symptoms appeared. Concentrations of macro and micronutrients in the terminal were higher in the affected needles than in unaffected needles. Symptoms were observed on trees ranging in height from 0.5 to 3.6 m.

The Potassium Imbalance Hypothesis

High K in foliage from affected shoots is a unifying trait for both winter and summer dieback. When plotted together, it is apparent that dieback is more related to high K levels (>10 g/kg) than with low B (figure 1). In some cases, the foliar K levels are 4 to 10 times higher than normal, therefore some wonder if there is an error in analysis. Terminal shoots of 7-56 seedlings contain high levels of K while lower branches are normal (table 2). Terminal shoots and branches of wildlings also have normal levels of K even though treated with the same herbicides and fertilizers as adjacent planted trees. The lack of high K in wildlings indicates a genetic basis; likely related to growth rate.

At one site, newly planted 7-56 seedlings were fertilized in March, 1996 with 56, 12 and 23 kg/ha of N,P,K, respectively, and summer dieback symptoms appeared in July of 1997. High concentrations of K were observed in September, 1997 with the mean of symptomatic shoots approaching 24 g/kg (Tim Martin, pers. Comm.). One sample had a value of about 48 g/kg K which is likely a record for loblolly pine. All elements were above commonly accepted "critical" levels. Although K toxicity is not known to occur in pine trees, fertilization with K can sometimes increase dieback symptoms (Kurkela 1983). At Bainbridge, GA, summer dieback symptoms were much lower after K was removed from fertigation (Tom Cooksey, pers. comm). Several scientists question the belief that high K levels in pine shoots do not cause nutrient imbalances. In fact, some believe that high K:Mg ratios can affect fast-growing pines (Beets and Jokela 1994). At one location, the K:Mg ratio in winter dieback shoots was 25 (table 2). Since high K values in foliage is obtained from a range of soil types (and sometimes from non-fertilized trees), we hypothesize that freeze injury in the cambial zone results in high K values in the shoot.

The Boron Deficiency Hypothesis

Some observers have noted a similarity to dieback symptoms caused by a deficiency in B. Damage to buds and tip dieback are typical symptoms of B deficiency. The pith is often completely brown and dieback symptoms may resemble that caused by pathogens (Stone 1990). Boron related dieback on pines in New Zealand typically occurs in midsummer after droughts but unusual cases of winter dieback can also occur (Will 1985).

Table 2— Nutrient content (g/kg) of selected elements in the foliage of the terminal shoots and lateral branch (height approximately 2 m) of loblolly pines in an intensively managed plantation (April 5, 2000). Dieback was observed only on the shoots of 7-56. Each mean represents a sample of three trees (means within a row having common letters are not significantly different α = 0.05)

	7-56		Wildling	
Nutrient	Shoot	Branch	Shoot	Branch
N	21.0a	20.0a	21.0a	20.0a
P	2.3a	0.8b	1.2b	0.8b
K	35.0a	3.7b	3.6b	3.6b
Mg	1.4a	1.1a	1.5a	1.0a
Ca	2.0a	2.4b	3.6a	2.8ab
B	0.022a	0.013b	0.020ab	0.016ab

Fertilization with B reduced summer dieback of loblolly pine in China (Zhu 1988, Zhou and others 1997) and reduced winter dieback symptoms in Africa (Vail and others 1961, Procter 1967). However, fertilizing the soil with B failed to ameliorate the problem in South Carolina (Clark 1974) and Alabama (personal comm. Scott Cameron). In some cases, shoots with winter dieback symptoms have B levels as high as 22 ppm (table 2). In other cases, shoots with no dieback symptoms have B levels as low as 5 ppm (figure 1).

Symptoms of B deficiency are usually characteristic, "although diagnosis may be confounded by variable foliar concentrations, erratic occurrence and possible climatic damages" (Stone 1990). In fact, "near the minimum end of the range, concentrations of apparently healthy trees may be less than those in visibly deficient trees" (Stone 1990). It should be noted that a "grossly unequal distribution" of B can exist in pine needles with high levels in the tips and low levels at the base (Stone 1990). In addition, improper sampling procedures could contaminate the foliage and could result in an upward bias.

Boron is important for lignification of tissue and non-lignified tissue is more sensitive to freezes than lignified tissue. Therefore, marginally B deficient pines can be damaged by a freeze (Kolari 1983). However, it is not clear if trees with B deficiency are actually more susceptible to the freeze or if the freeze simply caused the expression of the B deficient injury (Stone 1990). Boron may also be related to infection rate of certain diseases. Data from a greenhouse study with Eucalyptus indicated that seedlings were more susceptible to *Lasiodiplodia theobromae* when B concentrations in the leaves were below 30-35 ppm (Silveira and others 1996).

Prior to development of dieback symptoms, many of the intensively managed plantations were fertilized with N and P. Fertilization of macronutrients can sometimes induce dieback on low-B soils (Kolari 1983, Brockley 1990, Stone 1990). "Because B deficiency symptoms can develop rapidly following an interruption in B uptake, and because top dieback can have such an adverse effect on stem quality and value, it is recommended that B be added to N fertilizer when undertaking aerial fertilization projects in lodgepole pine forests when average foliar B concentrations are <15 ppm" (Brockly 1990). In the southern U.S., one company now uses a fertilizer mix that includes B along with N and P. This fertilizer combination was developed for use in intensively managed loblolly pine plantations to avoid problems with B deficiency.

Except for the high K levels in shoots, there appear to be many similarities between growth disturbances reported from Finland (Kolari 1983) and the dieback reported on loblolly pine in the U.S. The once-confusing dieback symptoms in Finland "Now appear largely, though not exclusively, due to B deficiency" (Stone 1990). Some wonder if the high levels of K in loblolly pine foliage could interfere with normal B metabolism.

The Abiotic Hypothesis

In addition to freezes and imbalances of B and K, other abiotic causes for dieback have been proposed. Some believe loblolly pine may be growing faster now than in the past due to elevated levels of carbon dioxide (Valentine and others 1999). Faster stem growth might be having an effect on the production of short-roots (Dean 2001) that might affect uptake of certain nutrients. Some allege that natural electrical point discharges from the shoot tip can interrupt the hardening process and increase freeze damage (Aurela and Punkkinen 1983). Others wonder if air pollution might cause dieback.

The Biotic Hypothesis

Lasiodiplodia theobromae is a ubiquitous facultative wound pathogen that has been associated with cankers and dieback of several trees including *Cupressus sempervirens* (Bruck and others 1990), *Eucalyptus citriodora* (Silveira and others 1996), *Liquidambar styraciflua* (Garren 1956), *Platanus occidentalis* (Lewis and van Arsdel 1976, Cooper and others 1977) and *Albizia falcataria* (Sharma and Sankaran 1988). This fungus has been found on slash pine seed in orchards (Fraedrich and Miller 1995) and on seedlings in loblolly pine and slash pine nurseries (Rowan 1982). Roy Hedden isolated this fungus from winter-dieback trees in South Carolina and Georgia and his student determined that inoculations cause dieback of 2-year-old loblolly pine seedlings (Jolley 2001).

Secondary fungi associated with dieback of loblolly in China include *Sphaeropsis sapinea* (Su and others 1991), however, loblolly pine is generally more resistant to this vectored fungus than other pines (Bega and others 1978, Swart and others 1988). Secondary insects are occasionally associated with winter dieback symptoms include Scolytid twig borers (*Pityophthorus pulicarius*) (Clark 1972).

The Two-factor Hypothesis

Due to the difference in symptom development for summer and winter dieback ("top-down" vs. "bottom-up"), it would not be surprising if two independent vectors were involved. It is possible that winter dieback is a function of freeze injury as suggested by Clark (1972). The combinations of rapid shoot growth followed by warm falls would likely increase the susceptibility of certain genotypes to injury from a –5^{o}C freeze. Freeze injury would likely increase the rate of infection from *Lasiodiplodia theobromae* while adjacent genotypes without freeze injury would not be infected.

In contrast, summer dieback symptoms appear to be less common and may be restricted to certain soil groups. Summer dieback might be due to an imbalance of nutrients resulting from either fertilization with only macronutrients, an imbalance between K and B, or perhaps an inadequate production of short feeder roots.

RECOMMENDATIONS

Only a few experiments have been conducted to test hypotheses related to dieback on loblolly pine. Trials should be conducted to determine if the high foliar K levels are a direct result of freeze injury. This might be accomplished by growing 7-56 in large containers in a heated greenhouse in Virginia and moving selected individuals outside just prior to a –10^{o} C (or colder) freeze. The foliage levels could be monitored to determine if the freeze affected nutrient levels in the shoot and sap.

Trials should be conducted to determine if K toxicity occurs on loblolly pine. Tree injectors could be used to apply potassium carbonate or potassium sulfate to 3-year-old seedlings. Rates applied should increase K levels in the foliage to 30 g/kg or greater. In addition, periodic nutrient analysis of a progeny test should be conducted to determine if 7-56 normally has high K levels in the terminal shoot.

Although a few B fertilizer trials have failed to produce beneficial effects, we have no information regarding the timing or amounts of B applied. We propose that prophylactic trials be conducted in young 7-56 plantations with the new N,P,B fertilizer (along with traditional N,P fertilizer). These trials should be conducted on the same soil groups where summer-dieback symptoms have occurred in the past. Greenhouse trials should be conducted to determine if K or B levels in loblolly pine shoots affect susceptibility to *Lasiodiplodia theobromae*.

In some conifers, dieback does not seem to cause a significant problem with wood quality (Bodner 1988). However, there is some concern that even small crooks can affect both the stumpage and lumber value. With loblolly pine, compression wood associated with dead terminals might reduce pulp yields by 1.5 to 2.5 percent (Hedden 1998). Plantations with severe winter dieback should be documented and later evaluated at harvest to determine the effects on wood quality.

SUMMARY

Evidence is yet not fully convincing for any of the above hypotheses. Each hypothesis has supporters. The next step is for scientists to conduct trials to determine the true causes of winter and summer dieback.

ACKNOWLEDGMENTS

We are grateful to Tim Martin for his considerable insight into the summer symptoms and to valuable comments from Scott Cameron, Tom Cooksey, Roy Hedden and Earl Stone.

REFERENCES

Aurela, A.M.; Punkkinen, R. 1983. Electric point discharges and atmospheric nitrogen dioxide in coniferous forests. Communicationes Instituti Forestalis Fenniae. 116: 143-152.

Beets, P.N.; Jokela, E.J. 1995. Upper mid-crown yellowing in Pinus radiata: some genetic and nutritional aspects associated with its occurrence. New Zealand Journal of Forestry Science. 24: 35-50.

Bega, R.V.; Smith, R.S.Jr.; Martinez, A.P.; Davis, C.J. 1978. Severe damage to Pinus radiata and P. pinaster by Diplodia pinea and Lophodermium spp. on Molokai and Lanai in Hawaii. Plant Disease Reporter. 62: 329-331.

Bodner, J. 1988. Forest dieback and wood quality. Holzforschung und Holzverwertung. 40: 97-100.

Brockley, R.P. 1990. Response of thinned, immature lodgepole pine to nitrogen and boron fertilization. Canadian Journal of Forest Research. 20: 579-585.

Bruck, R.I.; Solel, Z.; Ben-Ze'ev, I.S.; Zehavi, A. 1990. Diseases of Italian cypress caused by Botryodiplodia theobromae Pat. European Journal of Forest Pathology. 20: 392-396.

Clark, E.W. 1972. The role of Pityophthorus pulicarius Zimmerman in tip dieback of young loblolly pine. Journal of the Georgia Entomological Society. 7(2): 151-152.

Dean, T.J. 2001. Potential effect of stand structure on belowground allocation. Forest Science. 47: 69-76.

Fraedrich, S.W.; Miller, T. 1995. Mycoflora associated with slash pine seeds from cones collected at seed orchards and cone-processing facilities in the southeastern USA. European Journal of Forest Pathology. 25: 73-82.

Garren, K.H. 1956. Possible relation of Diplodia theobromae to leader dieback of sweetgum suggested by artificially induced infections. Plant Disease Reporter. 40: 1124-1127.

Hedden, R. 1998. Impact of Nantucket pine tip moth attack on loblolly pine – a South-wide summary. In: Waldrop, T.A., ed. Proceedings of the Ninth biennial southern silvicultural research conference; 1997 February 25-27, Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 569-572.

Hodge, G.R.; Weir, R.J. 1993. Freezing stress tolerance of hardy and tender families of loblolly pine. Canadian Journal of Forest Research. 23: 1892-1899.

Jolley, L.W. 2001. Tip dieback associated with Lasiodiplodia theobromae infection in loblolly pine plantations. Clemson, SC: Clemson University. M.S. thesis.

Kolari, K.K. (ed.). 1983. Growth Disturbances of Forest Trees. Communicationes Instituti Forestalis Fenniae. 116. 208.

Kurkela, T. 1983. Early observations on die-back of Scots pine in the fertilization experiments at Kivisuo. Communicationes Instituti Forestalis Fenniae. 116: 10-13.

Lewis, R.; Arsdel, E.P. van. 1976. Disease complex in Texas A&M University campus sycamores. In: Proc. of the American Phytopathological Society. 2: 137.

Martin, T.; Blakeslee, G. 1998. Needle and shoot blight of loblolly pine. In: Forest Biology Research Cooperative 2nd Annual Report. University of Florida. School of Forest Resources and Conservation: 4-11.

Mexal, J.G.; Timmis, R.; Morris, W.G. 1979. Cold-hardiness of containerized loblolly pine seedlings. Southern Journal of Applied Forestry. 3: 15-19.

Procter, J. 1967. A nutritional disorder of pine. Commonwealth Forestry Review. 46: 145-154.

Read, D.J. 1967. Dieback disease of Pines with special reference to Corsican Pine, Pinus nigra var. calabrica Schn. II. The relationship between frost resistance, microclimate and disease. Forestry 40: 83-97.

Rowan, S.J. 1982. Tip dieback of loblolly pine. Plant Disease. 66: 258-259.

Sharma, J.K.; Sankaran, K.V.; 1988. Incidence and severity of Botryodiplodia die-back in plantations of Albizia falcataria in Kerala, India. Forest Ecology and Management. 24: 43-58.

Silveira, R.L.V.A.; Krugner, T.L.; Silveira, R.I.; Goncalves, A.N.; 1996. Effect of boron on the susceptibility of Eucalyptus citriodora to Botryosphaeria ribis and Lasiodiplodia theobromae. Fitopatologia Brasileira 21: 482-485.

South, D.B.; Donald, D.G.M.; Rakestraw, J.L. 1993. Effect of nursery culture and bud status on freeze injury to Pinus taeda and Pinus elliottii seedlings. South African Forestry Journal 166: 37-45.

Stone, E. 1990. Boron deficiency and excess in forest trees: a review. Forest Ecology and Management 37 :49-75.

Su, K.J.; Tan, S.S.; Deng, Q. 1991. Studies on symptoms and causative agents of dieback of exotic pines in China. Forest Pest and Disease. 1: 2-5.

Swart, W.J.; Wingfield, M.J.; Knox-Davies, P.S. 1988. Relative susceptibility to Sphaeropsis sapinea of six Pinus spp. cultivated in South Africa. European Journal of Forest Pathology. 18: 184-189.

Tangwa, J.L.; Chamshama, S.A.O.; Nsolomo, V.R. 1988. Dieback disorder in Pinus patula, P. elliottii and P. caribaea at Sao Hill, southern Tanzania. Commonwealth Forestry Review 1988 67: 263-268.

Vail, J.W.; Parry, M.S.; Calton, W.E. 1961. Boron-deficiency dieback in Pines. Plant and Soil. 14:393-398.

Valentine, H.T.; Amateis, R.L.; Burkhart, H.E.; Gregoire, T.G.; Hollinger, D.Y.; MacFarlane, D.W. 1999. Projecting the Growth of Loblolly Pine in a Changing Atmosphere, Southern Journal of Applied Forestry. 23(4) :212–216.

Will, G. 1985 Nutrient deficiencies and fertilizer use in New Zealand exotic forests. New Zealand Forest Service. FRI Bulletin 97. 53 p.

Zhou, J.L.; He, Z.X.; Luo, M.G.; Zhang, Q.R.; Yang, M.; Zuo, Y.X. 1997. Studies on the incidence and control method for dried-up die-back of loblolly pine. Forest Research. 10: 360-364.

Zhu, S.K. 1988. Control of witches' broom in slash pine and loblolly pine through borax application. Journal of Zhejiang Forestry Science and Technology. 8(2): 38-39.

GLAZE DAMAGE IN 13- TO 18-YEAR-OLD, NATURAL, EVEN-AGED STANDS OF LOBLOLLY PINES IN SOUTHEASTERN ARKANSAS

Michael D. Cain and Michael G. Shelton[1]

Abstract—In late December 1998, a severe winter storm deposited 2.1 inches of precipitation on the Crossett Experimental Forest in southeastern Arkansas. Ice, in the form of glaze, accumulated on needles and branches of trees, and resulted in visual damage to sapling and pulpwood-sized pines. Within 60 days after the storm, damage was assessed within naturally regenerated, even-aged stands of loblolly pines (*Pinus taeda* L.) that ranged in age from 13 to 18 years. In all stands, >50 percent of pines were undamaged. When damage occurred in unthinned 13- and 18-year-old stands, pines were mostly affected by bending of the main stem. In thinned 15-year-old stands, damage was mainly in the form of branch loss. Stem breakage most often occurred when pines were 6 to 8 inches d.b.h. The probability of crown loss increased as d.b.h. increased; whereas, the probability of a bent main stem decreased with increasing d.b.h.

INTRODUCTION

Severe ice storms are fairly common in southeastern Arkansas, occurring three times (1974, 1979, and 1994) in 20 years (Guo 1999). During such storms, freezing rain or sleet accumulates as ice on trees. Affected trees can be uprooted, bent, or have their branches and stems broken. When ice storms cause substantial damage to pine stands, future volume production will likely be reduced and hardwoods may gain a competitive advantage over the pines (Halverson and Guldin 1995).

Since the occurrence and severity of ice storms are not predictable, landowners need information on the type and extent of damage that might be expected in their forest stands. The immediate effect of ice damage in loblolly pine (*Pinus taeda* L.) plantations has been extensively reported (McKellar 1942, Brender and Romancier 1960, Shepard 1975 and 1978, Fountain and Burnett 1979), but a literature search revealed no published information derived from natural, even-aged stands of loblolly pine. An ice storm in December 1998 resulted in eye-catching damage and gave the appearance of disaster in 13- to 18-year-old stands of naturally regenerated loblolly pines in southeastern Arkansas. This incident provided an opportunity to quantitatively evaluate the damage caused by ice in young natural pine stands.

METHODS

Study Area

Ice damage assessments were made within six natural, even-aged loblolly pine stands located within a 0.5-mile radius on the Upper Coastal Plain in southeastern Arkansas. Soils are Bude (Glossaquic Fragiudalf) and Providence (Typic Fragiudalf) silt loams with a site index of 85 to 90 feet for loblolly pine at age 50 years (USDA 1979).

Pines in these six stands represented three age classes—13, 15, and 18 years. Although shortleaf pines (*Pinus echinata* Mill.) were present in four of the six stands, their contribution was only 2 percent of total basal area. Each of the six stands contained 5 acres, and they originated on clearcut areas that measured either 660 feet by 330 feet or 1320 feet by 165 feet, with the long axes oriented north to south. Before regenerating naturally, these six areas were occupied by uneven-aged stands of loblolly and shortleaf pines that ranged up to 28 inches d.b.h. with about 100 pines per acre and about 9,000 board feet (Doyle scale) sawlog volume per acre. On four areas, merchantable-sized (>3.5 inches d.b.h.) pines were harvested in spring 1981. On two of these clearcuts, 18-year-old pine stands developed from seeds dispersed before harvest. The other two stands seeded with pines 15 years earlier after mowing a 3-year-old rough of vines, shrubs, and brambles that arose after clearcutting. The two 13-year-old stands developed from seeds dispersed during clearcutting of uneven-aged loblolly and shortleaf pines in autumn 1985.

Stand History

Once regenerated, the two 13-year-old stands and the two 18-year-old stands remained undisturbed until the ice storm of 1998. The two 15-year-old stands were intensively managed by applying herbicides to control competing vegetation for the first 5 years after pine establishment from seed, by precommercial thinning to a residual density of 500 pines per acre at age 5, and by commercial thinning from below at age 14 to leave 200 dominant and codominant pines per acre.

Before the ice storm, pine density and basal area were as follows: 1,222 stems and 124 square feet per acre in the unthinned 13-year-old stands; 200 stems and 79 square feet per acre in the commercially thinned 15-year-old

[1]Research Foresters, USDA Forest Service, Southern Research Station, Monticello, AR 71656-3516.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

stands; 1,192 stems and 173 square feet per acre in the unthinned 18-year-old stands. Mean quadratic d.b.h.'s were 4.3, 8.5, and 5.2 inches for the 13-, 15-, and 18-year-old stands, respectively.

Ice Storm

During 4 days (December 18-21, 1998) before the storm, weather conditions were mild, with high and low temperatures averaging 65° F and 42° F, respectively. During those 4 days, there was an accumulation of 1.2 inches of precipitation. On December 22, the high temperature was 40° F and the low temperature was 27° F. During the next 4 days, high temperatures ranged from 31 to 40° F and the lows ranged from 23 to 27° F. Between December 22 and 27, intermittent precipitation took the form of freezing rain or fine mist with a total accumulation of 2.1 inches. Ice deposits on forest vegetation were not measured, although radial thicknesses of 0.25 to 0.50 inch on pine needles, branches, and stems are not uncommon in this area (Burton 1981). The ice melted on December 27 and 28, when high and low temperatures rose to 49 and 41° F, respectively.

Measurements

Ice damage was assessed in late January through early February 1999. In the 13- and 18-year-old stands, fifty-one 0.01-acre temporary plots were systematically established. In the 15-year-old stand, damage assessments were conducted on 16 permanent 0.1-acre plots. Within these plot boundaries, each pine ≥1.0 inch d.b.h. was evaluated by type and extent of damage. The following damage categories were recognized: branch loss, crown loss, main stem broken, main stem bent, or tree root-sprung (roots loosened and the tree leaned from the base). For this study, branch loss was considered only if branch diameter was > 0.5 inch. The extent of branch and crown loss was estimated to the nearest 10 percent. Crown loss occurred when the central axis or main stem was broken. Branch loss occurred when individual branches were broken, but this category was never > 10 percent. Main stem breakage occurred when crown loss was 100 percent, and the stem broke below the lowest live branch. A root-sprung pine had large lateral roots displaced from the soil. The angle from the stem base to the terminal bud was estimated to the nearest 10 degrees for bent-stem and root-sprung damage categories. Some classes were mutually exclusive by definition: bent stem versus root sprung, and crown loss versus branch loss versus stem breakage. However, root-sprung pines or those with bent stems could also have crown and branch loss, but only two pines were classified as incurring multiple types of damage. Any mitigating circumstances (such as stem defects, forks, or damage caused by a neighboring tree) associated with a pine's damage were also recorded.

Data Analysis

Two plots, one in the 13-year-old stand and one in the 18-year-old stand, contained no pines and were dropped from analyses. To equalize the number of plots assessed for each age, the remaining 50 plots in the 13- and 18-year-old stands were grouped into 16 sets of three and one set of two based on their proximity to each other. Analyses included four severity classes: light (10- or 20-percent loss or degrees), moderate (30 to 50 percent loss or degrees), severe (over 50 percent loss or degrees), and lethal (main stem breakage or root-sprung). Only four trees were root-sprung, and all had tilts of > 60 degrees. Analysis of variance was conducted on the percentage of trees on each plot by damage type and severity class for a completely randomized design with stand age as the treatment variable. Plots were considered as pseudoreplicates (Hurlbert, 1984), which assumes that sampling error would be representative of the experimental error of true replicates. Percentage data were analyzed following arcsine square-root transformation, but only nontransformed percentages are reported. Differences among treatment

Table 1—Type and degree of ice damage in natural, even-aged loblolly pine stands in southeastern Arkansas

Type/degree of ice Damage	Stand age in years: 13	15	18	Mean Square Error	P
	Percent[a]				
Type of damage					
None	68.3a[b]	68.1a	53.6b	0.0443	0.04
Branch loss	1.8b	17.8a	0.9b	0.0098	<0.01
Crown loss	9.3a	10.3a	5.8b	0.0145	0.02
Main stem broken	1.1b	1.6ab	5.1a	0.0181	0.04
Main stem bent	19.5b	1.9c	34.2a	0.0517	<0.01
Tree root-sprung	0.0a	0.3a	0.4a	0.0024	0.42
Degree of damage					
None	68.3a	68.1a	53.6b	0.0443	0.04
Light	14.1b	24.4a	14.9b	0.0197	<0.01
Moderate	10.1a	5.0b	16.8a	0.0272	<0.01
Severve	6.4a	0.6b	9.2a	0.0245	<0.01
Lethal	1.1b	1.9ab	5.5a	0.0191	0.04

[a]Percent of all pines that were assessed.
[b]Row means followed by the same letter are not significantly different at the 0.05 level.

means were isolated using the Ryan-Einot-Gabriel-Welsch Multiple Range Test at $\alpha = 0.05$ (SAS Institute, Inc. 1989).

Logistic regression was used to test the effects of tree d.b.h. and plot basal area on the probability of damaged trees having either crown loss, stem breakage, or stem bending (Amateis and Burkhart 1996). This regression equation was based on 303 pines with moderate or severe damage in crown loss, stem breakage, or stem bending, and coefficients were calculated using the SAS procedure LOGISTIC (SAS Institute, Inc. 1989).

RESULTS AND DISCUSSION

The good news for forest landowners was that more than half the pines in these natural stands exhibited no apparent damage from the ice storm (table 1). The 18-year-old stands had a higher ($P = 0.04$) percentage (46.4 percent) of ice-damaged pines than did the 13- or 15-year-old stands. The most common damage category was a bent main stem for the 18-year-old pines (34.2 percent) and for the 13-year-old pines (19.5 percent). For pines in the 15-year-old stands, the greatest damage was branch loss (17.8 percent).

These differences among stands are attributed to the effects of thinning. Pines in the 15-year-old thinned stands were widely spaced with large crowns. Large crowns contributed to limb breakage and branch loss from ice accumulation because of their greater surface area. In contrast, pines in the unthinned 13- and 18-year-old stands were crowded with slender crowns. High pine density plus ice in these latter two stands resulted in a domino effect—as these unthinned pines began to bend from the ice, their neighbors were forced to bend in the same direction because of intertwined crowns. Of all tree and stand characteristics that contributed to ice storm damage (table 2), this neighboring-tree effect was highest ($P < 0.01$) in the 18-year-old stands (32.9 percent) when compared to the other stands. This type of damage was also greater ($P < 0.01$) in the 13- (13.6 percent) versus the 15-year-old stands (0.0 percent). In these natural stands, bole defects (such as cankers from *Cronartium fusiforme* Hedg. & Hunt) and stem forks were minor contributors to subsequent ice damage on trees (table 2).

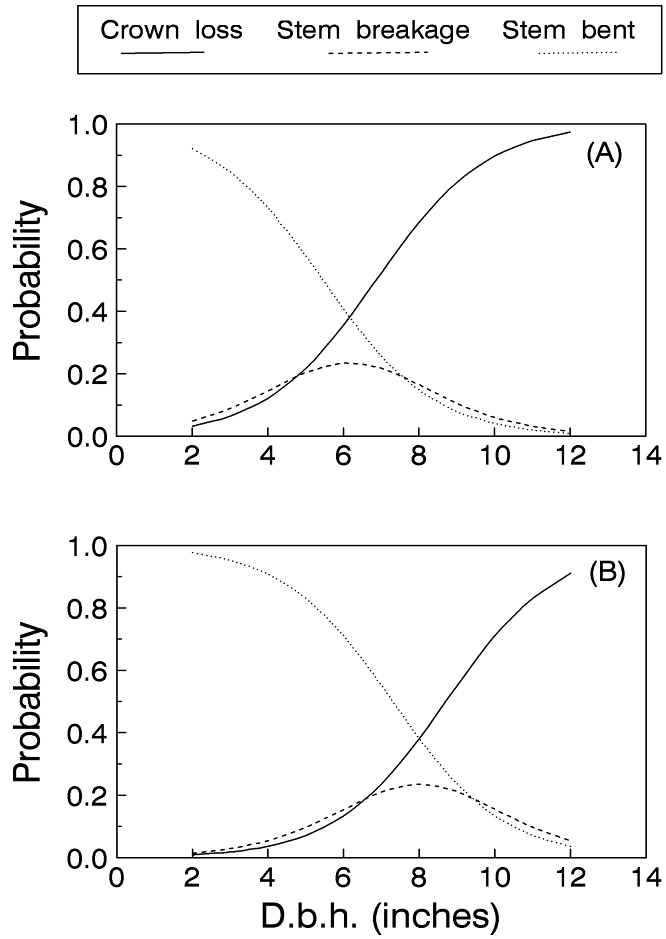


Figure 1—Predicted probabilities for crown loss, stem breakage, and stem bending caused by an ice storm in natural, even-aged loblolly pine stands at two basal-area levels: (A) 80 square feet per acre, (B) 140 square feet per acre. Results are based on 303 pines with moderate or severe damage.

Moderate to severe ice damage was greater ($P < 0.01$) in the 13- (16.5 percent) and 18-year-old (26.0 percent) stands as compared to the 15-year-old (5.6 percent) stands (table 1). Although the degree of damage rated as lethal was < 6 percent of the pines in any stand, Amateis

Table 2—Tree and stand characteristics that contributed to ice damage in natural, even-aged loblolly pine stands in southeastern Arkansas

Tree and stand characteristics	Stand age in years: 13	15	18	Mean Square Error	P
	Percent[a]				
None	85.3b[b]	98.8a	65.6c	0.0620	<0.01
Stem defects	0.6a	0.6a	1.3a	0.0073	0.47
Stem fork	0.5a	0.6a	0.2a	0.0040	0.59
Damage from neighboring pines	13.6b	0.0c	32.9a	0.0597	<0.01

[a]Percent of all pines that were assessed.

[b]Row means followed by the same letter are not significantly different at the 0.05 level.

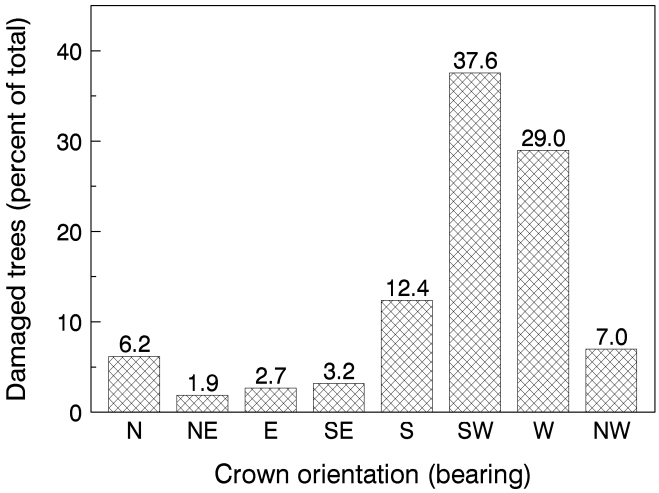


Figure 2—Crown orientation of loblolly pines that were bent, broken, or root-sprung by an ice storm in natural, even-aged stands. Results are based on 372 pines.

and Burkhart (1996) considered glaze damage that was >50 percent on loblolly pines to be so severe that the trees would soon die. Using their criterion in the present study, about 8 percent of ice-damaged pines in the 13-year-old stands and 15 percent in the 18-year-old stands would likely die.

The probability that a damaged tree will have crown loss, stem breakage, or stem bending can be determined from the following series of equations:

$$P_c = \exp(-3.106 + 0.704D - 0.022B)/\{1+ \exp(-3.106 + 0.704D - 0.022B)\} \quad (1)$$

$$P_s = \exp(-2.126 + 0.704D - 0.022B)/\{1+ \exp(-2.126 +0.704D - 0.022B)\} - P_c \quad (2)$$

$$P_b = 1-P_c-P_s \quad (3)$$

where P_c, P_s, and P_b are the probability the damaged tree will have crown loss, stem breakage, or stem bending, respectively; D is d.b.h. (inches); B is plot basal area (square feet per acre); and the regression coefficients were determined using logistic regression. All regression coefficients had Wald chi-squares of ≥26 and the probability of a larger value occurring by chance was <0.01 in all cases. The logistic regression had an R-square of 0.38.

These equations were solved for a reasonable range of d.b.h. values and two levels of basal area; the predicted probabilities are illustrated in figure 1. These equations suggest that stem breakage in natural loblolly pine stands under severe ice loading is most likely to occur at a d.b.h. of 6 inches when basal area is 80 square feet per acre or at a d.b.h. of 8 inches when basal area is 140 square feet per acre. Stem breakage is less likely at higher basal areas because the greater number of pines prevents stems from bending to the point of breaking. For both of these moderate to high basal area levels, the probability of crown loss was greater as d.b.h. increased. Conversely, the probability of stem bending declined as d.b.h. increased. These results are similar to those reported by Shepard (1975) in row-thinned loblolly pine plantations that were ice damaged in north Louisiana.

For pines that were bent or leaning as a result of the 1998 ice storm, crown orientation was generally constant. Fully 79 percent of these damaged pines had their crowns oriented in a southerly to westerly direction (figure 2), suggesting that prevailing winds during the storm were from the north and east. Consistency in the direction of lean would facilitate removal of the damaged trees through the use of directional felling.

MANAGEMENT IMPLICATIONS

After an ice storm, forest managers must determine the extent of damaged trees by conducting an inventory. Although merchantability standards vary across the South, about 5 cords of pulpwood or 1,000 board feet (Scribner scale) must be removed per acre to generate a merchantable harvest (Hyman 1985). In the present study, the volume in severely damaged pines >4 inches d.b.h. was estimated to be 0.9, 0.3, and 5.7 cords per acre in the 13-, 15-, and 18-year-old stands, respectively. Consequently, only pines in the 18-year-old stand were marked for a combination salvage and improvement thinning.

Merchantability of damaged trees may be of less importance than preventing an insect infestation. According to Hyman (1985), the greatest hazard to ice-damaged pine stands is the threat of southern pine beetles (*Dendroctonus frontalis* Zimm.). That threat is compounded by the fact that pine stands with basal areas in excess of 100 square feet per acre are highly susceptible to bark beetle infestation (Hicks 1981). In this study, basal area for the unthinned stands averaged 150 square feet per acre, thereby posing an increased risk of infestation to the remaining timber unless salvaged.

Pines in the 15-year-old thinned stands had larger mean diameters and suffered less bending but more branch loss from the ice storm than the higher density pines in the unthinned 13- or 18-year-old stands. These results suggest that early thinning in natural loblolly pine stands is advantageous by not only improving diameter growth but also by reducing the potential of catastrophic loss from periodic ice storms. Natural disturbances such as tornadoes, hurricanes, and ice storms often cause a drop in stumpage prices because of an overabundant supply of salvaged timber. But when forest landowners schedule thinnings outside the parameters of these natural disasters, they are able to take advantage of higher stumpage prices and reduce their probability of loss.

LITERATURE CITED

Amateis, R.L.; Burkhart, H.E. 1996. Impact of heavy glaze in a loblolly pine spacing trial. Southern Journal of Applied Forestry. 20: 151–155.

Brender, E.V.; Romancier, R.M. 1960. Glaze damage in loblolly pine plantations. Southern Lumberman. 201(2513): 168.

Burton, J.D. 1981. Thinning and pruning influence glaze damage in a loblolly pine plantation. Res. Note SO–264. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 4 p.

Fountain, M.S.; Burnett, F.E. 1979. Ice damage to plantation-grown loblolly pine in south Arkansas. Arkansas Farm Research. 28(3): 3.

Guo, Y. 1999. Ice storm damage to a sweetgum plantation fertilized with nitrogen and phosphorus. Southern Journal of Applied Forestry. 23: 224–229.

Halverson, H.G.; Guldin, J.M. 1995. Effects of a severe ice storm on mature loblolly pine stands in north Mississippi. In: Edwards, M.Boyd, comp. Proceedings of the eighth biennial southern silvicultural research conference; 1994 November 1–3; Auburn, AL. Gen. Tech. Rep. SRS–1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 147–153.

Hicks, R.R., Jr. 1981. Climate, site, and stand factors. In: Thatcher, R.C. [and others], eds. The southern pine beetle. Tech. Bull. 1631. Washington, DC: U.S. Department of Agriculture, Forest Service, Science and Education Administration: 55–68.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs. 54: 187–211.

Hyman, L. 1985. After the iceman cometh. Alabama's Treasured Forests. 4(2): 10–11.

McKellar, A.D. 1942. Ice damage to slash pine, longleaf pine, and loblolly pine plantations in the Piedmont section of Georgia. Journal of Forestry. 40: 794–797.

SAS Institute Inc. 1989. SAS/STAT user's guide. Version 6. 4th ed. Cary, NC: SAS Institute Inc. 846 p. Vol. 2.

Shepard, R.K., Jr. 1975. Ice storm damage to loblolly pine in northern Louisiana. Journal of Forestry. 73: 420–423.

Shepard, R.K., Jr. 1978. Ice storm damage to thinned loblolly pine plantations in northern Louisiana. Southern Journal of Applied Forestry. 2: 83–85.

U.S. Department of Agriculture. 1979. Soil survey of Ashley County, Arkansas. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service and Forest Service. 92 p. + maps. In cooperation with: The Arkansas Agricultural Experiment Station.

Long-Term Ecophysiology

Moderator:

ERIC JOKELA
University of Florida

SPECIAL SESSION: LONG-TERM ECOPHYSIOLOGY OF LOBLOLLY PINE

Session Coordinators: Eric J. Jokela, University of Florida and Phillip M. Dougherty, Westvaco Corporation

The natural range of loblolly pine is extensive, encompassing 15 southern and mid-Atlantic States from Florida to Delaware and west to eastern Texas and southeastern Oklahoma. Loblolly pine is the most important commercial species in this region, and it is found on more than 13 million ha and a wide variety of soil types. Throughout its natural range, intensive silvicultural practices have been used to enhance forest productivity and health. Considerable investments have been made over the last three decades in applied research programs emphasizing site preparation (mechanical, chemical), understory competition control, regeneration, fertilization, thinning, pest relationships, growth and yield, and genetic tree improvement as a basis for developing sound management strategies for this species.

Similarly, wide arrays of process-level research investigations have been conducted in the South to better understand the production ecology of loblolly pine. A special session of the 11th Biennial Southern Silvicultural Research Conference was organized to provide a forum for an exchange of ideas and a synthesis of knowledge on the ecophysiology of loblolly pine using long-term regional data sets. Five papers, summarizing the effects of intensive silvicultural practices on stand development, leaf area dynamics, productivity, wood quality and growth efficiency (aboveground production/leaf area), were presented. The session provided a unique opportunity to advance our understanding of how ecophysiological processes that control and limit loblolly pine productivity varied across climates, soils and management intensities. The presentations, based on long-term experiments conducted in North Carolina, Georgia, Florida, Louisiana and Oklahoma utilized a common variable format for examining key relationships. Abstracts of these presentations are presented in this volume and efforts are underway to publish the papers and an accompanying synthesis in the refereed literature.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

LONG-TERM TRENDS IN LOBLOLLY PINE SITE PRODUCTIVITY AND STAND CHARACTERISTICS OBSERVED AT THE IMPAC RESEARCH SITE IN ALACHUA COUNTY, FLORIDA

Timothy A. Martin, Eric J. Jokela[1]

While nutrient availability is a dominant factor controlling leaf area development and pine productivity in the southeastern USA, few studies have explored the long-term interactions among nutrient inputs, canopy foliage production, and aboveground biomass production. In order to address these questions, the Intensive Management Practices Assessment Center (IMPAC) southern pine "growth potential" experiment was established 6 miles northeast of Gainesville, Florida.

Soils at the experimental site are sandy, siliceous, hyperthermic Ultic Alaquods. In a typical profile, the spodic horizon occurs at 10-20 in, with an argillic horizon at 35-45 in. The experiment was planted in January, 1983, and consists of factorial combinations of species (loblolly and slash pine), fertilization (repeated or none) and understory weed control (complete or none), replicated three times. This resulted in four treatment combinations: control (C), fertilizer only (F), weed control only (W), and fertilizer combined with weed control (FW). Fertilization treatments were applied annually for ages 1-11 years, with cumulative rates of elemental application over the 11 year period as follows: N (321 lb/ac), P (128), K (283), Ca (96), Mg (64), Mn (2.7), Fe (2.7), Zn (2.7), Cu (0.4), B (0.4). The fertilization treatments were curtailed from ages 12-15 yr, then were re-initiated for ages 16-18 yr, with cumulative, three-year elemental application rates of: N (650 lb/ac), P (77), K (100), Mn (1.0), Cu (0.4), Fe (2.0), Zn (0.8), B (0.4), Mo (0.008). Biomass harvests at ages 4 and 13 yr were used to develop allometric relationships between diameter and aboveground biomass components, which were combined with annual inventories to estimate aboveground biomass production. Monthly litterfall collections starting at age 6 yr were used to estimate foliage biomass production and leaf area index (LAI). Although data were collected for both loblolly and slash pine, only loblolly pine results will be presented in this paper.

In general, growth responses due to silvicultural treatments were large over the entire study period. For example, at age 18 yr the FW treatment had an exhibited site index of 82 ft (base age 25 yr), compared to 58 ft in the untreated control. Age 18 yr total inside bark stem volume accumulation in the FW, F, W and C treatments were 3672, 3269, 2994 and 1394 ft^3/ac, respectively. Silvicultural treatments also tended to accelerate stand developmental processes. For example, at age 18 yr, 48 percent of stand stem volume in the FW treatment was in 9 in dbh or larger trees, compared to only 17 percent of the volume in the C treatment. Culmination of mean annual increment (i.e., "biological rotation age") occurred at approximately age 12 yr and 250 ft^3/ac/yr in the FW treatment, and age 18 yr and 78 ft^3 ac/yr in the C treatment. Density-related mortality was also accelerated in plots receiving silvicultural treatments. This density-related mortality became apparent at about age 16 yr in the F, W and FW treatments, but had not begun by age 18 yr in the C treatment. Self-thinning began at a Reineke stand density index (SDI) of about 360 (80 percent of maximum). Stand basal area of the F, W and FW treatments at the onset of self-thinning was 172, 159 and 192 ft^2/ac, respectively.

Leaf area development was also strongly impacted by silvicultural treatments, and was particularly responsive to nutrient additions. Projected LAI at age 11 yrs (just prior to the cessation of fertilization treatments) was approximately 3.3 in the F and FW treatments, compared to 2.7 and 1.2 in the W and C treatments, respectively. During the five years without fertilization (ages 11-16 yr), LAI in the F and FW treatments declined by approximately 15 percent, remained steady in the W treatment, and continued aggrading in the C treatment. LAI of the F and FW treatments responded dramatically to refertilization at age 16 yr, increasing from 3.1 to 3.5 and 2.9 to 3.3, respectively, in the year following the retreatment.

LAI across all treatments was strongly correlated with stand basal area, but the slope of this relationship declined with stand development (age 6 yr: LAI = 0.033 * stand BA, r^2 = 0.99; 16 yr LAI = 0.019 * stand BA, r^2 = 0.98). The relationship between stem volume production and LAI (i.e. stemwood growth efficiency) was strong, but also varied with stand development. At age 7-9 yr and 10-11 yr, average growth efficiency was 37.3 and 31.9 ft^3 ac/yr/LAI, but by age 14-16 had declined to 16.1 ft^3 ac/yr/LAI.

Wood quality parameters were impacted by tree age as well as cultural treatments. Tree ring earlywood / latewood ratios declined and ring specific gravity increased from age 4 yr to 10 yr. Ring specific gravity in the W treatment increased at a greater rate than in other treatments. The transition from juvenile to mature wood (defined as the age at which ring specific gravity > = 0.5) occurred at age 7 yr in the W treatment, and at age 8 yr in the F and FW treatments. Ring specific gravity reached 0.5 by age 8 yr in the C treatment, but fluctuated around the 0.5 point at age 9 and 10 yr, while specific gravity remained well above 0.5 after age 8 yr in the F, W and FW treatments.

---

[1]Professors, School of Forest Resources and Conservation, University of Florida, Gainesville, Florida

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

LONG-TERM TRENDS IN LOBLOLLY PINE PRODUCTIVITY AND STAND CHARACTERISTICS IN RESPONSE TO STAND DENSITY AND FERTILIZATION IN THE WESTERN GULF REGION

M.A. Sword, J.L. Chambers, Z. Tang, T.J. Dean, and J.C. Goelz[1]

Two levels each of fertilization and stand density were established to create four environments in a 7-year-old loblolly pine plantation on a N and P deficient western Gulf Coastal Plain site in Louisiana. Levels of fertilization were no fertilization and application of 120 lb N and 134 lb P/ac. Levels of stand density were the original stocking (1,210 trees/ac), and row thinning for a residual stocking of 303 trees/ac. Six years later (age 13), basal areas and relative stand densities on the non-thinned (NT) and thinned (T) plots were 176 and 79 ft^2/ac and 90 and 37 percent, respectively. At age 14, 178 lb N, 45 lb P and 45 lb K/ac were broadcast on the previously fertilized (F) plots and a second thinning was conducted on the previously thinned plots to a residual relative density of 31 percent of maximum, which corresponded to 67 ft^2/ac. Long-term measurements of climate, growth, leaf area dynamics and foliar nutrition were initiated at age 11. The objectives of this paper are to describe stand productivity between age 11 and 17 and offer ecophysiological explanations for these growth trends.

Fertilization increased basal area 8 and 9 percent, and stem volume 15 and 20 percent at age 11 and 17, respectively. At age 11, basal areas on the NT and T plots were 161 and 62 ft^2/ac, respectively. After removal of 12 ft^2/ac with the second thinning at age 14, basal areas increased on the NT and T plots, reaching 191 and 87 ft^2/ac and relative densities of 98 and 41 percent, respectively, by age 17. Similar stem volume responses to thinning were observed between age 11 and 17.

Interaction between light and water availability, and subsequent leaf area responses appeared to control mortality, current annual increment (CAI), growth efficiency (GE), and diameter class distribution. On the NT plots, for example, relative densities were within the self-thinning range of 60 to 100 percent of maximum stand density (81 to 98 percent) between age 11 and 17. During this period, peak leaf area index (LAI) increased between age 11 and 14, and began to decline at age 15 with the onset of water deficit and mortality. Specifically, annual soil water deficits at age 11 through 17 were 3.6, 7.3, 7.0, 4.7, 12.0, 10.6 and 15.9 in, respectively. Mortality for the entire period between age 11 and 15 was 5.5 percent; while mortality at age 16 alone was 7.0 percent. Water deficit at age 15 may have increased the rate of fascicle senescence, created a shortage of assimilate and increased self-thinning. Persistence of a high relative density and the simultaneous occurrence of water deficit and accelerated mortality after age 14 suggests that tree survival on the NT plots was dependent on a delicate balance between leaf area and assimilate supply.

In contrast to the NT plots, the T plots exhibited a positive curvilinear relationship between LAI and CAI ($R^2 = 0.4549$). This relationship improved with exclusion of data collected after age 14 when annual soil water deficits increased ($R^2 = 0.7235$). Variation associated with CAI on the T plots after age 14 may be attributed to the variable ability of individual plots to maintain normal levels of C fixation and growth when water deficit occurred. Below a LAI of approximately 3.25, this relationship was linear, but at LAI values greater than 3.25, a lower rate of CAI per unit LAI was observed both before and after the onset of water deficit. At our site, a LAI value of 3.25 may represent the point at which shading led to reduced lower crown light availability and less whole-crown C fixation, or the fraction of C allocated to sinks other than stem growth increased.

Growth efficiency (GE) between age 12 and 16 was expressed as the ratio of CAI and peak LAI. Year and stand density, but not fertilization affected GE. Average GE was 98 ft^3/ac/year at age 12. GE decreased to 30 and 86 ft^3/ac/year on the NT and T plots, respectively, at age 15, and increased to 78 and 91 ft^3/ac/year on the NT and T plots, respectively, at age 16. Declines in GE between age 12 and 15 may have been caused by temporary imbalances between CAI and peak LAI caused by self-thinning on the NT plots and operational thinning on the T plots. At age 16, the GE of the NT and T plots increased to 80 and 92 percent of that observed at age 12. It is likely that these gains in GE were caused by shoot and fascicle growth into canopy gaps created by self-thinning or operational thinning and subsequent increases in C fixation and volume growth.

In addition to volume increment, the diameter distribution of wood volume produced on the T plots changed over time in response to fertilization. Immediately before re-thinning at age 14, the majority of volume was in diameter classes less than 9 inches with the remaining 6 and 18 percent in the 9 to 12-inch diameter classes on the thinned, non-fertilized (TNF) and thinned, fertilized plots (TF), respectively. Three years later at age 17, 44 and 83 percent of the volume was in the 9 to 12-inch diameter classes on the TNF and TF plots, respectively. By age 17, fertilization on

[1] Plant Physiologist, U.S.D.A. Forest Service, Southern Research Station, Pineville, LA; Professors, School of Forestry, Wildlife and Fisheries, Louisiana State University, Baton Rouge, LA

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

the T plots not only produced a 19 percent increase in volume but added 89 percent more volume to the 9 to 12-inch diameter classes than to the diameter classes less than 9 inches. Following re-thinning, LAI equilibrated to pre-treatment levels after two years on the TNF plots and one year on the TF plots. Thus, when thinning and fertilization were applied together, fertilization increased the rate at which LAI was re-established. In addition to an increase in LAI, rapid equilibration of LAI may have hastened movement of volume into the 9 to 12-inch diameter classes on the TF plots when compared to the TNF plots between age 14 and 17.

At age 14 through 16, nutrient use efficiencies were calculated as the ratio of CAI and foliar N and P content (N NUE and P NUE). Nutrient use efficiencies were affected by year but not stand density or fertilization and averaged 1.9 and 26.1 ft^3/lb of foliar N and P, respectively, at age 14 and 15. At age 16, N NUE and P NUE increased to 3.2 and 42.5 ft^3/lb, respectively. Increases in N NUE and P NUE at age 16 occurred simultaneously with increases in GE and may have been associated with re-establishment of leaf area in canopy gaps caused by self-thinning and operational thinning. Although foliar concentrations of N and P were increased, nutrient use efficiencies were unaffected by fertilization. Thus, positive effects of fertilization on stand growth were likely caused by changes in leaf area, rather than nutrition enhancement of physiological responses.

In summary, between age 11 and 17 the productivity of plantation loblolly pine in four environments created by thinning and fertilization in central Louisiana appeared to be controlled by interaction among light, water and leaf area. Mechanisms of control differed by stand density, and effects of fertilization were manifested through leaf area responses.

CONSORTIUM FOR ACCELERATED PINE PRODUCTION STUDIES (CAPPS): LONG-TERM TRENDS IN LOBLOLLY PINE STAND PRODUCTIVITY AND CHARACTERISTICS IN GEORGIA

B.E. Borders, R. Will, R.L. Hendrick, D. Markewitz, T.B. Harrington, R.O. Teskey, and A. Clark[1]

Beginning in 1987, a series of long-term study plots were installed to determine the effects of annual nitrogen fertilization and complete control of competing vegetation on loblolly pine (*Pinus taeda* L.) stand growth and development. The study had two locations, one at the Dixon State Forest (DSF) near Waycross, GA on the lower coastal plain and the other at the B.F.Grant Experimental Forest (BFG) near Eatonton, GA on the Piedmont. The Dixon State Forest is characterized by long, hot, humid summers, with an average maximum July temperature of 33°C, and winters that are cool and fairly short, with an average January low temperature of 2.6°C. Average annual precipitation is about 130 cm, with about 60 percent falling between April and September. Soils are spodosols or ultisols that are arenic or grossarenic with slopes < 1 percent. The B. F. Grant location is characterized by warm to hot summers, with average July high temperature of 33°C, and moderately cold but highly variable winters, with average January low temperature of 2.2°C. Average annual precipitation is about 120 cm, with a maximum in early spring, a minimum in fall, and fairly even distribution for the rest of the year. Soils are clayey ultisols with slopes < 15 percent. Within each location there were two study sites separated by less than 6 kilometers.

Loblolly pine stands were established at a density of 680 trees/ac in 1987, 1989, and 1993 at the DSF location and in 1988, 1990, and 1995 at the BFG location. Half-sib family 7-56 was planted (North Carolina State Tree Improvement Cooperative) at the DSF locations and half-sib family 10-25 (North Carolina State Tree Improvement Cooperative) was planted at the BFG location. Two treatment blocks of each stand age were established at each of the two sites within locations. The exception was only one block of the 1995 planting was established at each site at BFG location. Each treatment block comprised four 0.15 ha plots that were assigned one of four treatments. The plot-level treatments were a factorial combination of fertilization and interspecific competition control. The fertilizer treatment (F) was an annual fertilization regime, consisting of 280 kg/ha diammonium phosphate and 112 kg ha^{-1} potassium chloride in the spring and 56 kg/ha ammonium nitrate in the summer of the first two years after establishment, followed by a minimum of 168 kg/ha ammonium nitrate in the spring of subsequent years. The interspecific competition control treatment (H) was an herbicide treatment to eliminate all competing vegetation throughout stand development. The HF treatment was the combination of fertilization and competition control. The control treatment (C), received neither fertilization or competition control.

Response of tree growth to the treatments has been exceptional. In general, the effects of competition control were greatest during early stand development, causing an upward shift in the relationship between stand age and growth. In contrast, the fertilization treatment increased the slope of the relationship between stand age and growth. Overall, the response of competition control was greater at the BFG location than it was on the DSF location. Average tree height at the DSF location at age 14 was 52, 68, 56, and 69 ft for the C, F, H, and HF treatments respectively. At the BFG location at age 13, average tree heights were 45, 55, 54, and 60 feet for the C, F, H, and HF treatments respectively. Total standing volume for the DSF location was 2665, 5645, 3745, 6342 ft^3/ac at age 14 for the C, F, H, and HF treatments and was 2363, 3438, 3703, 4579 ft^3/ac for the same treatments at the BFG location at age 13. Basal area at the DSF location was 109, 183, 146, and 199 ft^2/ac for the C, F, H, and HF stands at age 14 and was 111, 142, 151, 172 ft^2/ac for the same plots at the BFG location at age 13. Mean annual increment of the fastest growing HF plots at the DSF location appeared to have peaked around age 13 at approximately 490 ft^3/ac yr. The HF stands at the BFG location were approximately 350 ft^3/ac yr at age 13, but had not yet reached their maximum. Current annual increment (CAI) of the F and the HF plots at the DSF location approached 800 ft^3/ac yr between ages 8 and 12, and then decreased. The CAI of the C and H plots have remained fairly stable, below 400 ft^3/ac yr, over the same age range. At the BFG location, CAI was greater for the H treatment than for the F treatment until age 9. After age 9, the opposite was true. Maximum CAI for the HF plots at the BFG location was approximately 600 ft^3/ac yr. At both locations, there was a positive and fairly linear relationship between LAI and basal area. Height to live crown and basal area also were linearly related. Although crown length increased with stand basal area, the increase was much smaller than that for the relationship between height to live crown and basal area. At both locations, the average number of branches per whorl increased with increasing height, reaching a maximum of about 3.5 at the DSF location and 4.0 at the BFG location.

Profesor, Assistant Professor, Associate Professor, Assistant Professor, Associate Professor, Assistant Professor, Warnell School of Forest Resources, University of Georgia, Athens, GA 30602; Forest Products Technologist, USDA Forest Service, Southern Research Station, Athens, GA 30602, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Fertilization and competition control had significant positive effects on litterfall-based estimates of stand leaf area index (LAI). All-sided LAI for the foliage cohort that developed in 1998 was 3.9, 5.3, 5.7 and 7.0 for the C, F, H, and HF treatment plots, respectively, at the BFG location and 5.3, 7.6, 6.1 and 8.2 for the corresponding DSF plots. The effect of fertilization on LAI was strongest in older stands at both locations (significant interaction between age and fertilization). Fertilization increased LAI at the BFG location by 3 percent, 34 percent, and 28 percent for stand ages 4, 9 and 11, respectively, and at the DSF location by 8 percent, 38 percent and 79 percent for stand ages 6, 10 and 12. Competition control influenced LAI most dramatically in the youngest BFG stands (significant interaction between age and competition control), where competition control resulted in more than four times greater LAI at age four compared with 23 and 29 percent greater LAI at ages 9 and 11. Treatment and age effects on foliar nitrogen concentration closely paralleled effects on LAI. Stemwood growth per unit of leaf area (GE) declined with stand age, with mean values of 480, 220 and 203 ft^3/ac yr proj LAI for stand ages 4, 9 and 11 at the BFG location, and 277 to 226 to 189 ft^3/ac yr proj LAI for stand ages 6, 10, and 12 at the DSF location. The response of nitrogen use efficiency (NUE) to fertilization and competition control was similar to that of GE.

At both locations, GE and NUE decreased linearly with tree size, indicating the decreases in GE and NUE were probably due to tree size rather than tree age. At the DSF location, but not the BFG location, fertilized stands had greater GE when compared to unfertilized stands with equal sized trees indicating that fertilization had a positive effect on GE throughout stand development. For instance, fertilization increased GE expressed on a biomass basis from 3.4 to 4.5 tons bolewood prod. per ton leaf biomass for trees 11 m tall and from 2.1 to 2.5 tons bolewood prod. per ton leaf biomass for trees 17 m tall. For NUE, the differences between the fertilized and unfertilized stands of equal size were less than those for GE due to greater nitrogen concentration in the foliage of the fertilized stands.

LONG-TERM TRENDS IN PRODUCTIVITY AND STAND CHARACTERISTICS FOLLOWING THINNING OF A LOBLOLLY PINE STAND IN S.E. OKLAHOMA

T. Hennessey, P. Dougherty, R. Wittwer, T. Lynch, A. Clark, E. Lorenzi, R. Heinemann, and R. Holeman

EXTENDED ABSTRACT

A thinning levels study was initiated in Southeastern Oklahoma in the spring of 1984. The study was installed in a 9 year-old loblolly pine (Pinus taeda L.) plantation that contained 110 ft^2/ac of basal area. Thinning treatments consisted of (1) three control plots (BA-100) that were never thinned and contained an average of 860 trees/acre (tpa) at the beginning of the study (2) three plots that were thinned to approximately 25 percent of the original basal area (BA-25), basal area averaged 34 ft^2/ac after thinning and (3) three plots that were thinned to 50 percent (BA-50) of the original basal area, 54 ft^2/ac. In 1988 the BA-50 and BA-25 plots were rethinned to a basal area of 50 ft^2/ac. No other thinning has been done through age-24.

The control plots have attained a basal area of about 199 ft^2/ac and are now declining slightly. The BA-25 and BA-50 plots have basal areas between 140-150 ft^2/ac. Mortality has averaged about 34.7 tpa/year from age-10 through age-24 on the control plot, declining from 821 tpa to 335 tpa at age-24. Mortality losses in the BA-25 and BA-50 plots has been only 30-40 tpa over the entire study period. Standing inside bark volume in the control plots at age 24 is 47.9 cunits/ac, about 10 cunits/ac more than is present in the BA-25 and BA-50 treatments. About 5 cunits/ac were removed from the BA-50 treatment in the 1988 thinning. Average diameter at breast height (dbh) in the control plot is 9.8 inches and 33 percent of the trees in this treatment exceed 12 inches in dbh. Average tree size in the BA-25 and BA-50 is 15.9 inches with greater than 95 percent of the trees exceeding 12 inches in dbh. Mean annual increment (MAI) peaked at age 20 in the control plot at 225 cubic ft/ac/yr. MAI of the thinned plots have remained between 150 to 160 ft^3/ac/yr between ages 20 to 24 years but has not declined yet. Average ring width of the thinned plots exceeded 0.25 in/yr for four years following thinning, thus wood produced during this period would have less than four rings/inch. Average ring width of the control plot remained less than 0.25 in/yr since age 10 and has grown less than 1/8 in/yr since age-15. Ring specific gravity was not impacted by the thinning treatment and all treatments produced rings with similar latewood percentages. Year-to-year variation in ring specific gravity and latewood has been large and is related to the amount of late season rainfall. Periodic (3-year) annual increment (PAI) of the control plots have declined from a peak of 378 ft^3/ac/yr at age 14 to 36 ft^3/ac/yr at age 24. PAI of the BA-25 and BA-50 treatments peaked between 250 and 285 ft^3/ac/yr at age 17 but has remained at only slightly lower levels through age 24. This growth trend for thinned plots results in high stemwood production rates on large valuable trees. At age 22 the growth of trees in the control plots are supported by live crowns average 22 feet in length. Trees in the BA-25 and BA-50 plots have crown lengths that average 35 feet in length. Leaf area index (LAI) has remained between 3.0 to 4.8 in all treatments after basal area exceeded 130 ft^2/ac. Even the control plots that have attained basal areas of 199 ft^2/ac have retained LAI's in this range. However, growth efficiency (tons wood/acre/LAI) has declined with age. The decline in GE has been precipitous in the control plots since age 14. Growth efficiency of the thinned plots have declined only slightly from age 16 to age 24. This study concludes that early thinning on a site index 25 year 75 site has resulted in only minor reductions in total volume at age 24. The control plots contain 48.7 cunits that is distributed on 335 trees/acre. The BA-50 plots contains 39.1 cunits distributed on 117 trees/acre. This should have implications related to logging and processing cost. Average tree size is greatly influenced by thinning and thus product opportunities and stand value will be greatly influenced by early rotation thinning. Thinning does increase annual ring width, resulting in slightly less than four rings/inch for a period following the thin. Thus, lumber grade may be impacted. Thinning did not affect specific gravity so pulp yield per unit biomass would not be expected to differ across treatments.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

WATER AND NUTRIENT EFFECTS ON LOBLOLLY PINE PRODUCTION AND STAND DEVELOPMENT ON A SANDHILL SITE

H.L Allen, T.J. Albaugh, and K. Johnsen[1]

During the last decade, it has become apparent that production rates of pine plantations in the southeastern United States are far below levels that are biologically and economically optimal. By managing genetic and site resource effectively, production rates should exceed 350 ft^3/acre/year on most sites. In effort to better understand the ecophysiological constraints to production, the SETRES study was established in 1992 on a well-drained loamy sand site in Scotland County, NC. The experimental study consists of two levels of irrigation (none and optimum) and two levels of nutrient amendment (none and annual additions) replicated four times. Treatment plots measure 50 x 50 m with the internal 30 x 30 m as a measurement plot. Details of the experimental design, treatment regimes, and measurements are provided in Albaugh et al. 1998. Over the eight-year period since treatments were imposed, detailed assessments of individual tree and stand physiological, growth and development process have been examined.

Improved nutrition has had a very strong positive impact on production. Nitrogen, phosphorus, potassium, and boron were apparently the key limiting elements. Nutrient additions consistently increased peak leaf area by almost 100% over the eight years (figure 1).

Current annual volume increment was closely coupled with leaf area (figure 2). The combined gains in leaf area and growth efficiency (stemwood production per unit of leaf, GE) with nutrient additions resulted in a three-fold increase in annual stemwood production (80 to 240 ft^3/acre/year). After eight years of treatment, several water+nutrient plots had leaf area and current volume increment levels exceeding 3.5 and 350 ft^3/acre/year, respectively.

Over the eight years of study, GE varied from 55 to 70 ft^3/acre/year for control plots (figure 3). Water and nutrient additions increased GE but GE was not affected by stand age. GE reached 100 ft^3/acre/year on water+nutrient plots during the last two years of study.

Responses to water were much less than originally expected and there were no apparent interactions between water and nutrient additions. Although the soil has a very low water holding capacity, the rooting depth exceeded 10 feet apparently providing sufficient water for much of the growing season.

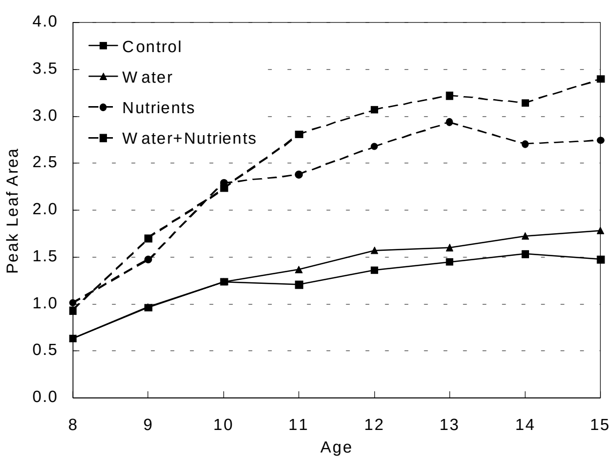


Figure 1— Peak leaf area with and without optimum water and nutrient additions in an eight- to 15-year old loblolly pine stand. By age 13, peak leaf area had stabilized at a maximum value of 1.5 on control plots, whereas leaf area on plots receiving nutrient additions averaged 3.0. Clearly, native nutrient availability now constrains leaf area levels rather than stocking.

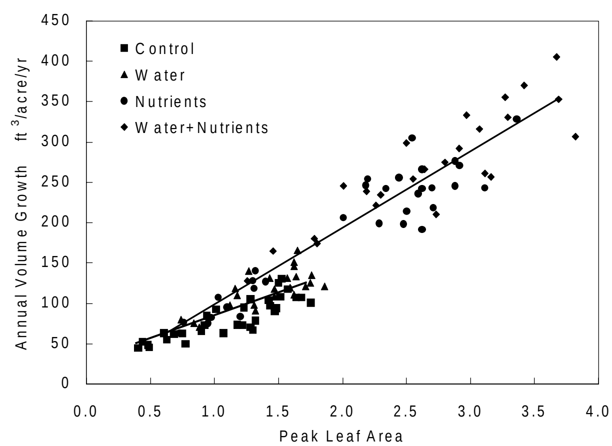


Figure 2—The relationship between current annual stemwood increment and peak leaf area across a range of water and nutrient availability conditions in an eight- to 15-year old loblolly pine stand.

[1] Professors, Department of Forestry, North Carolina State Univ., Raleigh, NC 276958 Project Leader, USDA Forest Service, Box 12254, Research Triangle Park, NC 27709, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

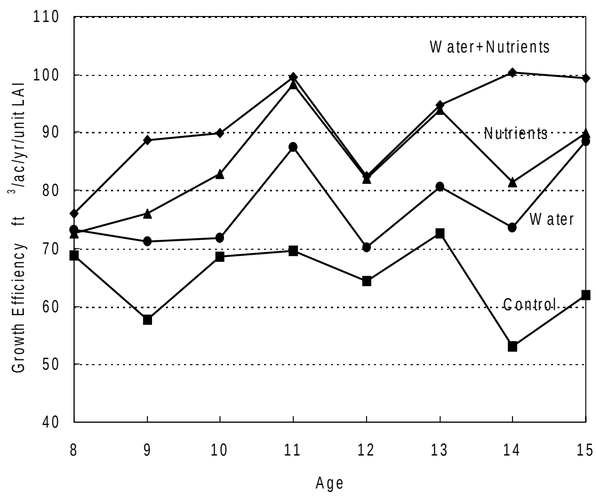


Figure 3— Growth efficiency (annual stemwood production per unit of peak leaf area) with and without water and nutrient additions in an eight- to 15-year old loblolly pine stand.

Interestingly, fine root production was not affected by the imposed treatments. However, aboveground production was dramatically increased with improved nutrition so a strong shift in biomass partitioning from roots to shoots was observed.

Estimates of nutrient use and soil nutrient uptake indicate that if the observed gains in production are to be sustained, soil nutrient availability will need to be maintained at a considerably higher level than naturally found on this site.

REFERENCES

Albaugh, T.J.; H.L. Allen; P.M. Dougherty; L.W. Kress; J.S. King. 1998. Leaf-area and above- and below-ground growth responses of loblolly pine to nutrient and water additions. Forest Science 44:317-328.

ECOSYSTEMS

SPECIES DIVERSITY IN PLANTED PINE AND NATURAL HARDWOODS 24 YEARS AFTER SHEARING AND CHIPPING ON THE CUMBERLAND PLATEAU, TN

Karen Kuers[1]

Abstract—Plant species richness in 24 year-old planted loblolly pine (*Pinus taeda* L.), eastern white pine (*Pinus strobus* L.), yellow-poplar (*Liriodendron tulipifera* L.), naturally regenerated hardwoods, and mature hardwoods was compared using the North Carolina Vegetation Survey protocol. Comparisons were made in plots established after shearing and on-site chipping of a low quality hardwood stand on the Cumberland Plateau near Sewanee, TN in 1976. In 3 of the 6 plots representing each species, stems over 1.3 meters tall were injected with herbicide during the winter after harvest. Six years after planting, half of each eastern white pine plot was cleaned by manually or chemically removing only those trees essential to release the overtopped white pines. Three additional plots were installed in 2000 in the surrounding mature forest. Data collected in 2000 included species presence and cover class for a log10 series of nested square subquadrats (0.01, 0.1, 1.0, 10, and 100 square meters) within a 900 square meter quadrat for each of the 0.4 hectare plots. A total of 159 plant species (excluding grasses) were encountered within the twenty-seven 900 square meter plots. Sixty-three were found in all 5 stand types. Thirty-nine were found in only one stand type, with the largest number (10) found in loblolly pine and yellow-poplar. Plant species richness beneath the loblolly pine was not significantly different from planted yellow-poplar, natural regeneration, or the surrounding older hardwood forest. Eastern white pine, however, exhibited reduced plant richness relative to the other stand types. The effects of tree injection on plant richness varied with stand type and plant form. While woody plant species declined slightly in all plot types, herbaceous species tended to decline in pine plots and increase in the hardwood plots. The effects of successive competition treatments on plant species richness in eastern white pine were cumulative (average 4.5 species per treatment).

INTRODUCTION

Many assumptions and beliefs exist regarding the effects of pine conversion on the biodiversity of our native hardwood forests. The public is concerned that replacing hardwoods with planted pine or using silvicultural practices such as competition control will reduce plant species diversity. While various studies have been initiated to address the effects of silvicultural practices on the floral diversity of harvested hardwood stands (Baker and Hodges 1998, Hammond and others 1998, McMinn 1998, Wender and others 1999) fewer studies have addressed understory composition of planted pine (e.g., Krochmal and Kologiski 1974), and none are available that compare the understory of planted pine to that of similar age hardwood stands on the Cumberland Plateau in Tennessee.

In the 1970's the Sewanee Silviculture Lab of the USDA Forest Service Southern Research Station initiated a series of studies to address land management opportunities for private landowners with cut-over, degraded hardwood stands. One such study (McGee 1980), investigated the potential of clear-felling by in-woods chipping, followed by planting one of two species of pine (loblolly and eastern white), yellow-poplar, or allowing natural regeneration. In addition to providing valuable tree growth information, this study (now 24 years-old), provided an excellent opportunity to compare the floral diversity under different planted species to that of natural hardwood regeneration. Since two different levels of tree removal were used, harvest to a 10 centimeter dbh and harvest to 10 centimeters with the injection of the smaller residual stems, it was also possible to test the effect of woody competition control on plant species richness.

The objectives of the research reported here were to determine the effects of 1) planting pine, planting yellow-poplar or natural hardwood regeneration and 2) control of woody competition at harvest on the plant richness (non-woody and woody vascular plants) of a low-quality hardwood stand on the Cumberland Plateau near Sewanee, TN.

STUDY AREA

The 15 hectare (37-acre) study area, is located on the Cumberland Plateau near Sewanee, TN (35°12'30"N and 85°55'W). It is typical of Landtype 1 (Undulating Sandstone Uplands) (Smalley 1982). The moderately deep to deep soils developed in loamy residuum from sandstone and some shale. Sandstone outcrops in places. The soils are classified as fine-loamy, siliceous, mesic Typic Hapludults. Elevation ranges from 579 to 594 meters. Annual precipitation, averaging 140 centimeters, is well distributed; September and October are the driest months.

The area was harvested in 1976 by shearing and chipping (McGee 1980). Prior to harvest, the stand consisted primarily of culls and low quality hardwood stems. The dominant

[1]Associate Professor of Forestry, Department of Forestry and Geology, The University of the South, Sewanee, TN, 37383

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

overstory species were white oak (*Quercus alba* L.) and scarlet oak (*Quercus coccinea* Muenchh.). Site index estimates ranged from 17 to 23 meters for oak, but accurate estimates were difficult to obtain because there were few suitable overstory trees (McGee 1980). The harvest removed 1200 tons of green chips and a total of 30 tie logs or sawlogs from the entire 15 hectare area. All stems = 10 centimeters dbh were removed from the site during the shearing, leaving 125 to 1480 stems per hectare (mostly 5 – 8 centimeters dbh).

After harvest, twenty-four 0.4 hectare (1-acre) plots were established and six plots were randomly selected for each of the following treatments: planting 1.0 loblolly pine (LP), planting 2.0 eastern white pine (EWP), planting 1.0 yellow-poplar (YP), and natural regeneration (NAT). Trees were planted at a 2.4 x 3 meter spacing. In three plots of each treatment, stems over 1.37 meters tall were injected (INJ) with herbicide during the winter after harvest. A square 0.1 hectare measurement subplot was established in the center of each plot. Six years after planting, half of each EWP plot was cleaned by manually or chemically removing only those trees necessary to release the overtopped white pines. The early growth and development of the trees have been reported in a series of publications (Hepp 1989, McGee 1980, McGee 1982, McGee 1986), the most recent of which was a report on a subset of the treatments after the fifteenth growing season (Dethero 1992).

METHODS

In the summer of 2000, a 900 square meter plot (30 meters x 30 meters) was established within the central measurement plot in each of the original 24 experimental plots. Three additional 0.4 hectare plots were established in regions of the adjacent forest that were not harvested in 1976 (UNCUT) to allow comparison of the diversity in the clear-cut plots to that of mature forest. A 900 square meter measurement plot was established in each.

A modification of the North Carolina Vegetation Survey protocol (Peet and others 1998) was used to compare the total plant diversity of the treatments. Each 900 square meter quadrat was subdivided into nine 10 x 10 square meter modules. Two series of smaller subplots (0.01, 0.1, 1.0, and 10 square meters) were nested within opposite corners of four of the nine 100 square meter modules.

The presence and cover class of each plant species were recorded for all nine 100 square meter modules within each treatment plot. In four of the modules, species presence was recorded within the two nested series of subplots. Thus for each species/treatment combination there were 3 replications of the 900 square meter plots, 27 of the 100 square meter subsamples (9 per plot) and 24 subsamples (8 per plot) for each of the smaller areas sampled (10, 1, 0.1, and 0.01 square meters).

In the fall of 2000, dbh, height class, and crown class for all stems = 1.3 meters tall (living and dead) were recorded by 100 square meter module for each of the twenty-seven 900 square meter measurement plots (only the basal area information will be included in this report).

Similarity of plant communities was investigated using the Czekanowsky Coefficient of Similarity (Czekanowski 1913). The Czekanowsky Coefficient includes both qualitative (presence/absence) and quantitative (abundance) data. The value used for species abundance was the number of 100 square meter plots in which a species was found rather than the actual number of stems. Coefficients range from 0 to 1, with 0 indicating no species in common, and 1 indicating the same number and same abundance present for each of the species.

Main effects (species; injection) and the interaction were tested at the a = 0.05 level using General Linear ANOVA models (SPSS). Duncan's Multiple Range Test was used to compare means when significant differences were detected.

RESULTS

A total of 159 plant species (excluding grasses) representing 119 genera and 24 families were encountered within the 27 900 square meter plots (table 1). These included 34 trees, 19 shrubs, 91 herbs, 9 vines, and 6 ferns. Sixty-three (40 percent) were found in all 5 plot types and 18 (11 percent) were found in all 27 of the measurement plots.

Thirty-nine (25 percent) of the identified species were found in only one plot type, the majority of which were herbs (25 species; table 2). The largest numbers of unique species (10) were found in LP and YP sites. The lowest numbers (6) were found in both UNCUT and NAT sites. Differences in numbers of unique species were due primarily to differences in numbers of herbs.

The Similarity Coefficient (Czenakowski 1913) based upon all plants in all 6 plots for each plot type indicated that the LP, YP, and NAT plots were more similar to each other than they were to the EWP plots (table 3). While coefficients averaged 0.84 among the non-EWP plots, the average similarity of EWP to the non-EWP plots was only 0.71. The coefficients for herbaceous species (0.66 average) were significantly lower than those for woody plants (O.84 average; $p < .0001$).

Table 1—Comparison of species richness (number of species) by plant form across twenty-seven 900 square meter plots (3 mature mixed-oak forest, and 6 each of 24 year-old loblolly pine, eastern white pine, yellow-poplar and natural regeneration)

	All Forms	Trees	Shrubs	Herbs	Vines	Ferns
Totals[a]	159	34	19	91	9	6
Common[b]	63	21	8	27	6	1
Ubiquitous[c]	18	8	4	4	2	0
Unique[d]	39	6	5	25	2	1

[a]Total number of species fouind in the 27 study plots
[b]Number of species that were fuound in all 5 plot types
[c]Number of species that were fuound in all 27 plots
[d]Number of species that were fuound in only one plot type

Table 2—Number of unique[a] species by plant form in mature mixed-oak forest (UNCUT), and 24-year-old loblolly pine (LP), eastern white pine (EWP), yellow-poplar (YP) and natural regeneration (NAT)

	Plant Form					
	All Forms	Trees	Shrubs	Herbs	Vines	Ferns
Uncut	6	1	1	4	0	0
EWP	7	3	0	2	2	0
LP	10	1	1	8	0	0
NAT	6	1	1	3	0	1
YP	10	0	2	8	0	0

[a] Species found in only one plot type

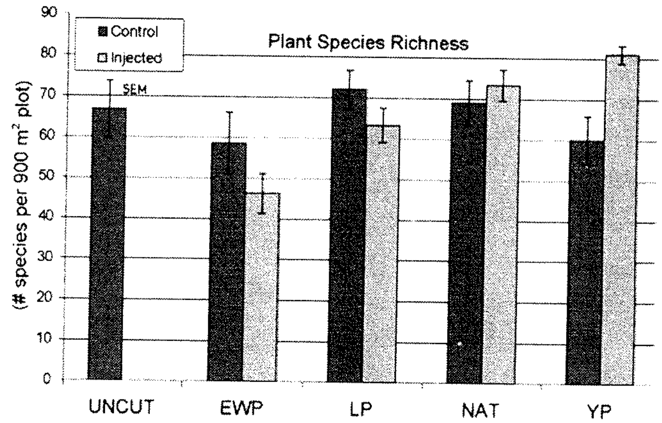


Figure 1—Average total plant richness of injected and non-inject 900 square meter plots of mature mixed-oak forest (UNCUT), and 24 year-old loblolly pine (LP), easter white pine (EWP), yellow-poplar (YP) and natural regeneration (NAT).

Coefficients comparing INJ to NON-INJ plots of the same species were 0.75 (YP), 0.80 (EWP), 0.83 (NAT), and 0.85 (LP).

Average plant richness per 900 square meters ranged from a low of 59 species in EWP to a high of 71.3 in LP (figure 1). Numbers in YP, UNCUT, and NAT were intermediate (61.7, 66.7, and 69.0 respectively).

The size of the area sampled had an impact on apparent effects of the treatments. For example, tree species richness averaged 20.2 per 900 square meters and was not affected by either species or injection. When based upon the smaller 100 square meter plots, however, tree species richness did differ among species, with richness in EWP lower than in the other species (11.0 versus 14.3 average).

Table 3–Comparison of plant community similarity between plots of 24 year-old lobololly pine (LP), eastern white pine (EWP), yellow-poplar (YP) and natural regeneration (NAT) using the Czekanowski Similarity Coefficient[a] (based upon six 900 square meter plots for each type)

	Czekanowski Coefficient			
Plot type	LP	EWP	YP	NAT
LP	-	.75	.82	.81
EWP	-	-	.70	.69
YP	-	-	-	.89
NAT	-	-	-	-

[a]The coefficient was calculated: $2 \sum \min (X_i, Y_i) / (\sum X_i + \sum Y_i)$ where X_i = # of 100 m^2 plots in which species i occurs in plot type X, Y_i = # of 100 m^2 plots in which species i occurs in plot type Y, and $(\min (X_i, Y_i))$ = the lesser # of 100 m^2 plots (type X or Y) in which species i occurs.

The effects of tree injection on total plant richness varied with plot type (figure 1). While the within-species trend was for pine sites to exhibit decreased richness with INJ and hardwood sites increased richness, only in YP was the difference statistically significant. Injection reduced the plant richness of the EWP(INJ) sites relative to all other treatments except EWP(NON-INJ) and YP(NON-INJ).

Woody species richness (shrubs + trees) was not significantly different in INJ and NON-INJ 900 square meter plots (figure 2), although there was a trend across all species for a reduction of approximately 3 species. While herbaceous species richness declined with INJ in pine plots by an average 8 species per 900 square meter plot, richness actually increased by an average of 8 species in the deciduous plots. (Only in YP was this difference significant at 0.05.)

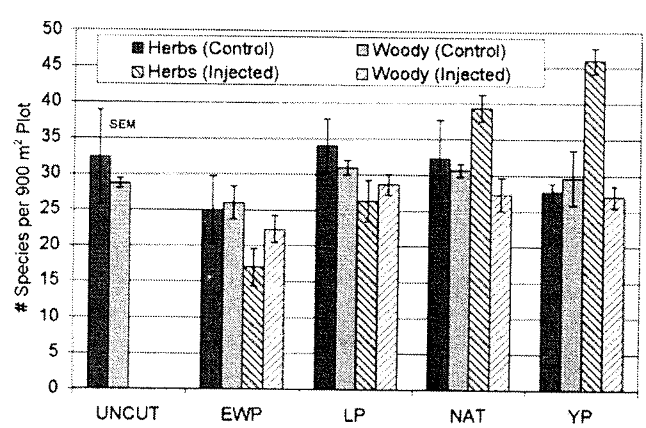


Figure 2—Average woody species richness (shrubs + trees) and herbaceous species richness (excluding grasses) of injected and non-injected 900 sq. meter plots of mature mixed-oak forest (UNCUT), and 24 year-old loblolly pine (LP), eastern white pine (EWP), yellow-poplar (YP) and natural regeneration (NAT).

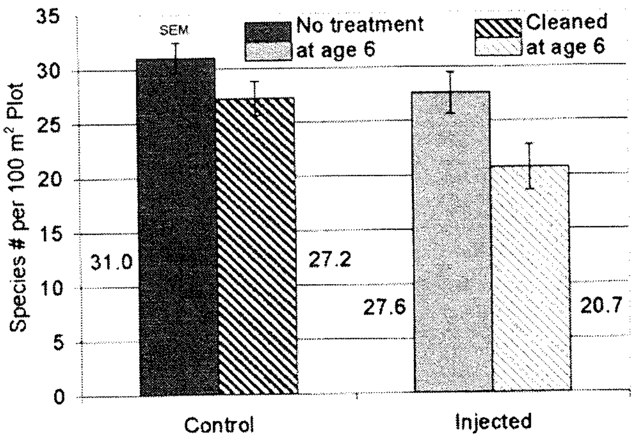


Figure 3—Effects of two successive competition treatments (immediately post harvest or at age 6) on the total plant species richness of 100 meter plots of eastern white pine (EWP).

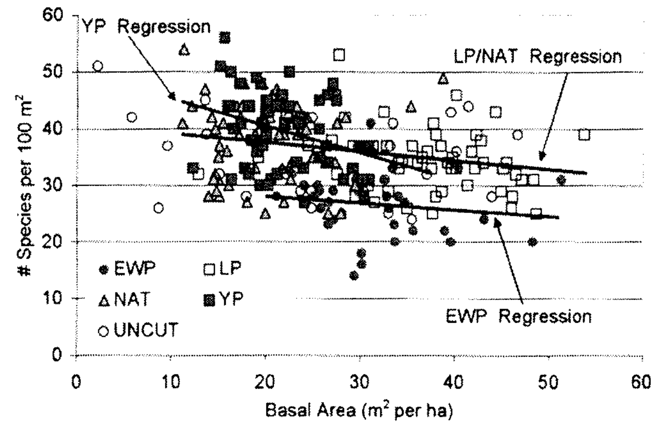


Figure 4—Relationship of plant species richness to the basal area of tall stems 1.3 meters tall within 100 square meter plots of mature mixed-oak forest (UNCUT), and 24 year-old loblolly pine (LP), eastern white pine (EWP), yellow-poplar (YP) and natural regeneration (NAT).

The effects of successive competition treatments on plant species richness in EWP were cumulative, with an average reduction of 4.5 species per treatment (figure 3). The timing of the treatment (immediately post harvest or at age 6) was not significant for the magnitude of the species change. However, the two treatments had different effects on the woody and herbaceous species. The species most impacted by the initial treatment were herbaceous (reduced by 3.8 species per 100 square meters versus 1.1 woody species). In contrast, the weeding at age 6 had little impact on the herbaceous species (0.8 species reduction), but did reduce the woody component by 3.6 species.

Current plot basal areas (all stems = 1.3 meters tall) were higher in the pine than in the hardwood plots. The NON-INJ plots averaged 30 square meters/hectare in the pines and 20 square meters/hectare in the hardwoods. INJ increased the overall basal area of the pines by 3 square meters/ hectare in EWP and 8 square meters/hectare in LP. INJ increased the average percentage of the total basal area that was pine from 58 to 69 percent in EWP and from 60 to 86 percent in LP. INJ decreased basal areas by an average of 1 square meter/hectare in both NAT and YP plots. Basal area in all of the hardwood plots was dominated by oaks (white, scarlet, and black (*Quercus velutina* Lam.)) except for some of the YP(INJ) plots which were dominated by YP.

Differences in plot BA (all stems = 1.3 meters tall) had little relationship with plant species richness in this study (figure 4). Only in YP was the slope of the regression significantly different from zero. However, there was a difference in the number of species per unit BA, as EWP stands exhibited a lower species number per given BA than all the other stand types, including LP. The relationship was similar if only pine basal area was considered in the analysis (data not shown).

DISCUSSION

Twenty-four year old clear-cut sites on the Cumberland Plateau planted to LP, YP, or allowed to regenerate naturally (NAT) to mixed hardwoods did not differ in plant species richness from the adjacent mature hardwood forests (UNCUT). These results are not surprising to those who have planted LP on hardwood sites and had to control the hardwood and herbaceous competition that develops in the young stands. Richness has been shown to increase immediately after harvest and decline with time (Baker and Hodges 1998, Hammond and others 1998). Twenty-four years have likely been sufficient at this site to return the species numbers to the levels of the surrounding mature stand.

While there was not a significant difference in the woody plant richness of the non-EWP plots, there was likely a change in the relative abundance of different species, a pattern found after harvest in Southern Appalachian forests (Oliver 1980, Parker and Swank 1982). Numbers of unique species (those found only in one plot type) were actually higher in the planted sites and lowest in the uncut forest and naturally regenerated plots.

Areas planted to EWP did exhibit reduced plant richness. One possible explanation for the difference in EWP is the high leaf area it supports and the reduced light levels at the forest floor. However, even EWP plots with reduced basal area (pine or hardwood) and presumably more open canopies exhibited fewer species than LP, YP, or UNCUT plots with similar basal areas (figure 4). Because other coniferous species such as Eastern hemlock (*Tsuga canadensis* (L.) Carr.) have been shown to influence species distributions through effects on soil properties (Beatty 1984), one future area of investigation will be potential differences in soil properties beneath the EWP relative to the other plots.

Studies have shown variable effects of competition control on species richness in pine plantations. While woody competition control had no effect on understory species richness in 12-14 year old LP plantations in the Virginia Piedmont, canopy woody plant richness was reduced by either woody plant or herbaceous control (Shabenberger and Zedaker 1999). While there was no effect of broadcast herbicide treatments on the overstory or understory plant richness in planted LP on the Georgia Piedmont after seven years (Boyd and others 1995), non-pine woody competition control increased forb and grass cover in 8 to 11 year-old longleaf pine (*Pinus palustris* Mill.) plantations (Harrington and Edwards 1999).

The injection of residual stems at harvest had a negative impact on species richness in the planted pine sites in this study, but resulted in an increase in richness in the hardwood sites. While the only difference that was statistically significant (a = 0.05) was the increase with INJ in the YP plots, the downward trend within the pines was very consistent, and with a larger number of samples would likely have shown statistically significant differences as well.

The difference in the response of richness in the pine and deciduous hardwood plots is possibly due to differences in the rate of full site occupancy in the INJ pines and hardwoods. Injection in the pines likely allowed the fast growing pines to fully occupy the sites and prevented the successful establishment of other species. The overall slower growth of hardwoods, and the removal of some of the hardwood basal area through injection in the INJ hardwood plots would have provided additional resources (light, moisture, etc.) for other species to become established.

The increased richness in the injected hardwood sites was due to herbaceous, not woody, species. Woody plants declined slightly in INJ plots of all species (figure 2). While changes in woody plant species were generally small (losses of 1 to 4 per 100 square meters), changes in herbaceous species ranged from –8 in pines to +18 in YP. Hammond and others (1998) also found that changes in woody plant diversity were generally less than those of herbaceous species after harvest of southern Appalachian mixed oak sites.

The plots with the highest species richness and the greatest increase in richness with injection were the YP(INJ) plots. This is possibly due to the increased light that passes through YP crowns relative to oaks. While YP actually dominated some of the YP(INJ) plots, oaks (white, scarlet, and black) dominated all of the YP(NON-INJ) plots as well as all of the NAT plots.

While one possible explanation for differences in species richness beneath the pines could be the effects of high pine basal area, the explanation does not appear to apply to the results of this study. There was no apparent relationship between species richness and either total or pine basal area at either the 900 square meter or 100 square meter plot size except a slight decline in YP (figure 4).

CONCLUSIONS

The effect of planting pine on plant species richness will depend upon the species of pine planted. Species numbers in 24-year-old LP on the Cumberland Plateau were not significantly different from planted YP, NAT, or the surrounding older hardwood forest. Planting EWP, however, did reduce plant diversity, and competition control increased the overall effect.

The study area did not receive any intermediate stand treatments other than the release of EWP at age 6. Since injection of competing stems at harvest caused slight reductions in species richness, it is possible that more intensive management would have a greater impact on plant richness. It is interesting to note, however, that injection of residuals at harvest actually appeared to increase richness in the hardwood stands. Thus silvicultural harvest of mixed–oak stands may tend to foster greater plant richness than harvests which leave more residual stems on the site.

ACKNOWLEDGMENTS

This study was made possible through a grant from the USDA Forest Service Southern Research Station. Many thanks to Charles E. McGee and the scientists at the USDA Forest Service Sewanee Silviculture Lab for their forethought and careful work in the design and implementation of the original study. Special thanks to Charles F. Grimes, Forest Service Technician, for his many hours of assistance in the collection and entry of data.

REFERENCES

Baker, J.C.; Hodges, J.D. 1998. Changes in woody stem species diversity over time following clearcutting in the Mississippi river floodplain. In: Waldrop, T.A. (ed.) Proceedings of the Ninth Biennial Southern Silvicultural Research Conference. February 25-27, 1997, Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S.Department of Agriculture, Forest Service, Southern Research Station. 468-472.

Beatty, S.W. 1984. Influence of microtopography and canopy species on spatial patterns of forest understory plants. Ecology. 65(5): 1406-1419.

Boyd, R.S.; Freeman, J.D.; Miller, J.H.; Edwards M.B. 1995. Forest herbicide influences on floristic diversity seven years after broadcast pine release in central Georgia, USA. New Forests 10(1): 17-34.

Czekanowski, J. 1913. Zarys Metod Statystycznyck. Warsaw.

Dethero, J.B. Jr. 1992. Stand development of white pine and competing vegetation on the Cumberland Plateau, TN. School of Forestry and Environmental Studies, Duke University. Masters thesis.

Hammond, D.N.; Smith, D.W.; Zedaker, S.M.; Wright, D.K.; Thompson, J.W. 1998. Floral diversity following harvest on southern Appalachian mixed oak sites. In: Waldrop, T.A. (ed.) Proceedings of the Ninth Biennial Southern Silvicultural Research Conference. February 25-27, 1997, Clemson, SC. Gen. Tech. Rep. SRS-20. Ashville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 461-465.

Harrington, T.B.; Edwards, M.B. 1999. Understory vegetation, resource availability, and litterfall responses to pine thinning and woody vegetation control in longleaf pine plantations. Canadian Journal of Forest Research. 29(7): 1055-1064.

Hepp, Todd E. 1989. Pine and Hardwood regeneration options on a Cumberland Plateau Site: An economic perspective. In: Waldrop, Thomas A. (ed.) Proceedings of Pine Hardwood Mixtures: A Symposium on Management and Ecology of the Type. 1989 April 18-19, Atlanta, GA, Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 223-229.

Krochmal, A.; Kologiski, R. 1974. Understory plants in a mature loblolly pine plantation in North Carolina. Research Note SE-208. USDA Forest Service Southeastern Forest Experiment Station, Asheville, NC. 8 p.

McGee, Charles E. 1980. Expanding options for reforestation of the Cumberland Plateau. Southern Journal of Applied Forestry. 4(4):158-162.

McGee, Charles E. 1982. Low quality hardwood stands. Opportunities for management in the interior uplands. Gen. Tech. Rep. SO-40. U.S.Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. 22 p.

McGee, Charles E. 1986. Regeneration after shear felling and chipping of upland hardwoods. Research Paper. SO-224. U.S.Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. 22 p.

McMinn, J.W. 1998. Influence of harvest variables on woody plant diversity in upper coastal plain mixed types. In: Waldrop, T.A. (ed.) Proceedings of the Ninth Biennial Southern Silvicultural Research Conference. February 25-27, 1997, Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S.Department of Agriculture Forest Service, Southern Research Station: 466-467.

Oliver, C.D. 1980. Forest development in North America following major disturbances. Forest Ecology Management. 3: 153-168.

Parker, G.R., and Swank, W.T. 1982. Tree species response to clear-cutting a southern Appalachian watershed. American Midland Nationalist. 108(2): 304-310.

Peet, R.K., Wentworth, T.R., and White, P.S. 1998. A flexible, multipurpose method for recording vegetation composition and structure. Castanea 63(3): 262-274.

Shabenberger, L.E., and Zedaker, S.M. 1999. Relationships between loblolly pine yield and woody plant diversity in Virginia Piedmont plantations. Canadian Journal of Forest Research. 29(7): 1065-1072.

Smalley, G.W. 1982. Classification and evaluation of forest sites on the mid-Cumberland Plateau. Gen. Tech. Rep. SO-38. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. 58 p.

Wender, B.W., Hood, S.M., Smith, D.W., Zedaker, S.M., and Loftis, D.L. 1999. Response of vascular plant communities to harvest in southern Appalachain mixed-oak forests: Two year results. In: Haywood, J.D. (ed.) Proceedings of the Tenth Biennial Southern Silvicultural Research Conference, February 16-18, 1999, Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 34-38.

INTEGRATION OF LANDSCAPE ECOSYSTEM CLASSIFICATION AND HISTORIC LAND RECORDS IN THE FRANCIS MARION NATIONAL FOREST

Peter U. Kennedy and Victor B. Shelburne[1]

Abstract—Geographic Information Systems (GIS) data and historical plats ranging from 1716 to 1894 in the Coastal Flatwoods Region of South Carolina were used to quantify changes on a temporal scale. Combining the historic plats and associated witness trees (trees marking the boundaries of historic plats) with an existing database of the soils and other attributes was the basis for exploring possible site types as defined by Landscape Ecosystem Classification (LEC) and historic vegetation.

Field plots were established using locations of the witness trees from the historic plats. The witness trees could then be used as a basis of comparison between past and present vegetation. From the field plots, four clusters of vegetation were delineated using Detrended Correspondence Analysis (DECORANA) and Two-way Indicator Species Analysis (TWINSPAN). Discriminant analysis revealed thickness of the A horizon, presence/absence of a B horizon, Landform Index (LI), and Terrain Shape Index (TSI) as discriminating variables in the model. These four site units revealed a soil moisture gradient ranging from very poorly drained soils to moderately well drained soils.

The historic witness tree data set was dominated by longleaf pine (70 percent). The comparison of historic witness trees to present vegetation showed a drastic decrease in longleaf across the landscape due to past management practices and the suppression of fire.

INTRODUCTION

The South Carolina Coastal Plain is home to some of the most biologically diverse ecosystems in the world. These ecosystems have been significantly altered by natural and anthropogenic activity over the past 10,000 years. Public pressures have prompted the United States Forest Service to manage National Forests as ecosystems (Brenner and Jordan 1991) having an array of uses and functions, rather than timber stands used only for the extraction of commodities.

An understanding of these ecosystems during presettlement times will prove to be invaluable for better management today. The objective of this study was to use Landscape Ecosystem Classification (LEC) and historical data to model presettlement (natural state) plant communities. This knowledge will assist in long-term studies of past ecological processes and provide a basis for the study of present modern day plant communities (Schafale and Harcombe 1982).

METHODS AND DATA ANALYSIS

Study Area

Field data were collected on 32 plots within Francis Marion National Forest (FMNF). These plots were located in areas of close proximity to locations of known witness trees from the historic plats. Witness tree data and the field plots encompassed some of the site units as defined by the Hilly Coastal Plain Province and Coastal Flatwoods Region LEC models for South Carolina Coastal Plain Province (Petitgout 1995).

Annual precipitation in the study area averages 47 inches and ranges from 39 to 55 inches. Summertime temperatures range from 65° to 90° F with temperatures in excess of 100° F occurring a few days most years. The average winter temperature is about 48° F with maximum and minimum temperatures of 60° and 35° F, respectively. The growing season is roughly 260 days (Long 1980).

Creating a Database

This project began with the creation of GIS (ARC/INFO) layers incorporating historic vegetation data and other cultural features from historic plats for areas in the FMNF. Fifty historic grant plats were initially acquired from the Charleston and Berkeley County records and digitized into the database, each as its own coverage (layer). These data were added to the already existing GIS database for FMNF. All of the vegetation, cultural features, and other relevant information were captured in the GIS. This information could then be used to perform spatial analyses and comparisons of the present vegetation and features in the FMNF versus the historic vegetation and features.

Sampling Procedures

In order to describe forest types in the areas defined by the witness trees, Landscape Ecosystem Classification (LEC) methodology was used to quantify vegetation and the underlying physical factors that help to discriminate among forest types. In preparation of going into the field, a map

[1]Graduate Research Assistant, Associate Professor, Department of Forest Resources, Clemson University, Clemson, SC 29634, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

was created overlaying witness trees with the USFS forest type coverage using GIS. This map was used to identify mature stands (LEC calls for "steady-state") located in close proximity to the historic witness trees. Very few "steady-state" stands could be found throughout the FMNF, much less in the areas of witness trees where the study was restricted. This can be attributed to management practices and more so to the damage done to the forest by hurricane Hugo in 1989.

A circular 0.04 hectare plot was established in areas as delineated by witness tree data. Trees (no smaller than 4.5 inches diameter at breast height (dbh)), were measured for dbh and height for the entire 0.04 hectare plot. Seedlings, vines and herbaceous covers were sampled over the entire plot using a density class rating (Blanquet 1932/1951). Saplings (1-4 inches dbh) were tallied for a smaller subplot (0.01 hectare) in the center of the 0.04 hectare plot.

Soil samples were collected in three locations on each plot using a soil auger. Depth of the A and B horizons (C when there was no B) were determined in the field by averaging the three samples. Depth to maximum clay was also determined in the field. Maximum clay was a subjective measurement taken at the depth where the best ribbon could be made for the soil sample. No maximum clay was recorded for those soils determined in the field not to have B horizons. Soil samples from the A and B horizons (C horizon if no B existed) were composited for each plot. Texture analysis was performed in the lab, without the removal of organic matter, using the pipette method (Foth and others 1971).

Recent and ongoing studies in the southeastern Coastal Plain have shown that small differences in topography and landform can make a difference in the vegetative communities found and the site units derived (Stich 1994). For this reason, Terrain Shape Index (TSI) and Landform Index (LI) (McNab 1989, 1993) were recorded on each plot to determine the significance of these variables in distinguishing among site units.

Analytical Procedures

Vegetation data were summarized by species stratum for each plot. Relative density, relative basal area, and importance value 200 ((relative density + relative basal area / 2) x 100) were calculated by stratum for trees and saplings. Importance values were determined using relative frequency for seedlings, shrubs, and herbs. Where a single species occurred in more than one stratum, each instance was treated as a unique species or 'pseudospecies' (Carter 1994).

Detrended Correspondence Analysis (DECORANA) was the method of ordination used to analyze the vegetation data (Hill 1979a). TWINSPAN (Hill 1979b) was also used to analyze the vegetation data. DECORANA and TWINSPAN were used in the software package PCORD©. PCORD© is a windows based program used for multivariate analysis of ecological data (McCune and Mefford 1995).

Stepwise discriminant analysis and discriminant analysis (SAS 1990) were used to analyze the physical variables associated with the field plots. The soil variables used in the analysis were depth to maximum clay (inches), depth of soil horizon (inches), humus thickness (inches), and horizon texture. The landform variables used were Landform Index and Terrain Shape Index (McNab 1989, 1993). Stepwise discriminant analysis was used to determine the discriminating variables at the 0.20 significance level. The validity of the discriminant function was determined using resubstitution and cross-validation (SAS 1990).

Due to the small sample size of witness trees and dominance of longleaf pine in the sample, they were analyzed by looking at various relative frequency scenarios. The indicator or diagnostic species found in the ordination and classification were also compared to the witness trees and relative frequencies were observed. All of the basic statistics involving numbers of trees and area involved were conducting using GIS.

RESULTS AND DISCUSSION

Ordination and Cluster Analysis

The primary data matrix consisted of 32 plots and 307 species. A number of ordinations were performed to determine possible relationships between vegetation and the corresponding axes that represented a discernible environmental gradient. The first ordination was run using the exact groups delineated by TWINSPAN and then subsequent trials were performed in an attempt to achieve better classification and agreement between the ordination/ cluster analysis and the discriminant analysis. Personal judgement was used during group assignment based on knowledge of plot composition and characteristics.

Presence/absence data were analyzed for 32 plots and 307 species. DECORANA and TWINSPAN identified 4 groups. Axis 1 had a beta diversity of 3.8 standard deviations while axis 2 had a beta diversity of 4.3 standard deviations. A complete turnover in species should occur after 4 standard deviations along any of the axes (Hill and Gauch 1980). Numerous plots demonstrated disagreement in clustering by DECORANA and TWINSPAN. After studying the data closer, the clusters were modified. This was done systematically on a plot by plot basis and then rerunning the ordination as each cluster was altered by a single plot. Figure 1 represents the clusters that were the basis for the most accurate model using discriminant analysis.

Discriminant Analysis

Stepwise discriminant analyses were utilized to determine the significant physical variables that could be used to discriminate among the groups found using ordination and classification. Discriminating variables were identified and a linear model was created. Sixteen variables were entered during the stepwise discriminant analysis procedure. They were Landform Index (LI), Terrain Shape Index (TSI), root mat thickness (inches), depth to maximum clay (inches), A horizon thickness (inches), B horizon thickness (inches), presence/absence of a B horizon and relative proportions of sand, silt and clay in the A, B and C horizons. Five variables proved to be significant at the 0.20 level. These variables were (1) Landform Index (2) Terrain Shape Index

Table 1—Discriminant function equations of four ecological site units produced by discriminant analysis

Multiplier	Ecological Site Unit Hydric	Mesic	Submesic	Intermediate
	Coefficient			
Constant	-17.48	-16.13	-5.64	-10.58
Landform Index	-77.05	143.33	53.42	-7.86
TSI	562.64	-2.23	298.33	530.98
B Horizon (Pres 1/Absence 0)	1.08	-0.30	0.41	1.37
A Horizon Thickness (inches)	1.19	0.27	0.55	0.61
Percent Sand (C)	-0.58	0.05	-0.22	-0.51

Table 2—Field model discriminant function equations of 4 ecological site units produced by discriminant analysis

Multiplier	Ecological Site Unit Hydric	Mesic	Submesic	Intermediate
	Coefficient			
Constant	-12.17	-16.09	-4.9	-6.52
Landform Index	99.95	141.52	61.87	11.89
TSI	223.77	24.9	171.62	234.86
B Horizon (Pres 1/Absence 0)	-0.16	-0.20	-0.05	0.28
A Horizon (inches)	0.53	0.32	0.31	0.03

(3) thickness of the A horizon (4) presence/absence of B horizon and (5) percent sand in the C horizon.

Discriminant analysis was then used to determine how accurately these five significant physical variables could be used to classify the data into the four clusters delineated in figure 1. The discriminant function had a resubstitution classification rate of 88 percent and misclassified three plots. The cross-validation classification rate was 77 percent with seven plots misclassified. This represents the best model that could be created using all available data. The discriminant functions (model) for the initial run are in table 1. The correct site classification is the site unit with the highest sum of all the products of each site unit equation. In the discriminant model, a 1 represented the presence of a B horizon and a 0 represented the absence of a B horizon.

A second discriminant analysis procedure was performed to generate a model that could be used in the field. This field model was created using only those variables that were conducive to field measurement (table 2). Four of the five variables found to be significant (0.20) in the original stepwise discriminant analysis procedure were adequate for field sampling. These variables were (1) Landform Index (2) Terrain Shape Index (3) depth of the A horizon and (4) presence/absence of B horizon. The discriminant function had a classification success of 80 percent using resubstitution and 69 percent using cross-validation.

Axis Interpretation

The clusters found by DECORANA exhibited a moisture gradient across the landscape. The first axis in the ordination relates to a moisture gradient (figure 1). This can be seen in the vegetation but corresponding environmental and soil variables are difficult to interpret. Several studies have shown soil texture and depth to clay to be a surrogate for soil moisture (Marks and Harcombe 1981, Jones 1989) but no clear relationship can be seen here. There can be no doubt that the underlying factors affecting moisture on the sites are heavily correlated with soil texture and topography. However, the history of past land uses and disturbance in the study make it difficult to determine these relationships among the vegetation, soils, and landform.

Ecological Site Unit Descriptions

Each cluster defined by ordination/classification revealed a distinguishable group of vegetation and set of associated physical variables. This assemblage of species and physical variables forms the basis of the site units. Due to the wide range of sites sampled, the presence or lack of a B horizon was the most significant environmental variable discriminating among site units.

Hydric Site Unit

The hydric site unit is characterized by an overstory of swamp tupelo (*Nyssa biflora*) and pondcypress (*Taxodium ascendens*). Fetterbush (*Lyonia lucida*) and Virginia willow (*Itea virginica*) dominated the understory. There was no dominant herbaceous cover in the hydric site unit.

In the hydric site unit the B horizon thickness averaged 31.7 inches. The average A thickness was 14.9 inches. The average Landform Index (LI) was 0.14. The average TSI for the hydric plots was 0.01.

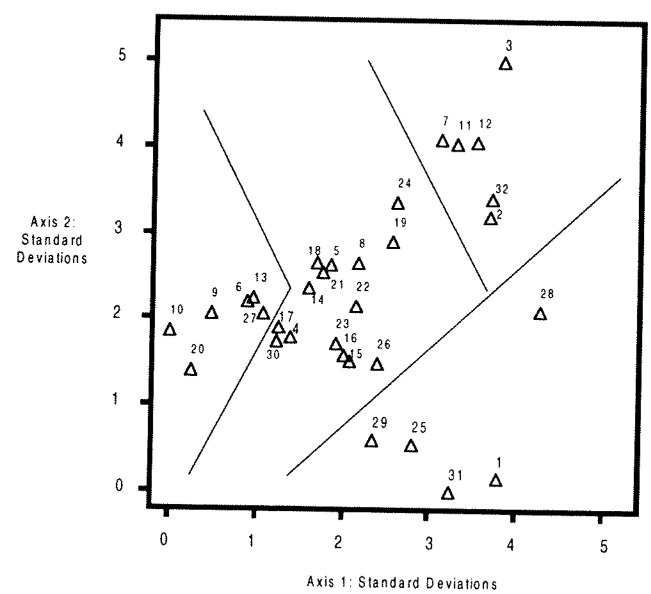


Figure 1—Presence/Absence Ordination of 32 plots and 307 species.

Mesic Site Unit

There was no overstory vegetation associated with the mesic site unit. The understory was dominated by the shrub American beauty-berry (*Callicarpa americana*) and flowering dogwood (*Cornus florida*) in the sapling stage. The herbaceous cover consisted of three vines: supplejack (*Berchemia scandens*), Virginia *creeper (Parthenocissus quinquefolia*) and variety of muscadine (*Vitis labrusca*).

Landform Index had a mean of 0.22 in the mesic site unit. The average Terrain Shape Index (TSI) was 0.007. The average A horizon thickness for the mesic site unit was 2.7 inches. The average B horizon thickness was 43.2 inches. There was no C horizon within the upper 50 inches of the soils in this site unit.

Submesic Site Unit

Tupelo (*Nyssa sylvatica*) dominated the overstory of the submesic site unit and Water oak (*Quercus nigra*) saplings characterized the understory. The herbaceous covers were predominantly red chokeberry (*Aronia arbutifolia*), and netted chain fern (*Woodwardia areolata*).

The submesic site units had an average A horizon thickness of 9.0 inches and an average B horizon of 34.0 inches. The average Landform Index was 0.1 and the average Terrain Shape Index was 0.01.

Intermediate Site Unit

The intermediate site unit had an overstory dominated by longleaf pine (*Pinus palustris)* and a shrub-like oak, running oak (*Quercus pumila*) characterized the understory. The herbaceous covers consisted of black-root (*Pterocaulon pycnostachyum)* and bracken fern (*Pteridium aquilinum).*

This site unit had an average C horizon thickness of 37.8 inches and 70.6 percent sand in the C horizon. The average A horizon thickness was 5.1 inches, there was no B horizon found in this site unit and Terrain Shape Index and Landform Index averaged 0.01 and 0.07, respectively.

Historic Witness Trees Associated with Field Plots

All historic witness trees located within 200 meters of the field plots were compared with the present day species occurring in the field plots. This portion of the analysis was accomplished using the GIS since none of the historic trees could be located on the ground.

Relative frequency of witness trees and present day trees was also examined. In the intermediate site unit, longleaf pine was represented in 100 percent of the plots by witness trees and present day trees. Tupelo (swamp or water tupelo) occurred in 25 percent of the intermediate site unit plots as a witness tree but did not occur in the present day field sampling.

In the sub-mesic site unit, Longleaf pine was represented on 87 percent of the plots by witness trees and 33 percent by present day trees. Pondcypress or baldcypress (*Taxodium distichum*) occurred 27 percent as a witness tree and 13 percent as a present day tree. Red maple (*Acer rubrum*) occurred only 6 percent as a witness tree but 60 percent as a present day tree. Blackgum was represented on 6 percent of the plots by witness trees and 47 percent of the plots by present day trees. As a witness tree, r. oak (red oak) occurred on 6 percent of the plots while oaks (in general) occurred on 100 percent of the plots as a present day tree. Bay (sweet bay (*Magnolia virginiana*)and beech (*Fagus grandifolia*)both had 6 percent occurrence as a witness tree in this site unit while they did not occur as a present day tree.

In the mesic site unit, longleaf pine as a witness tree occurred in every plot (100 percent) but did not occur as a present day tree. Water oak was represented by witness trees in 25 percent of the mesic site unit plots and 50 percent as a present day tree. Poplar (yellow-poplar (*Liriodendron tulipifera*)) occurred in 25 percent of the plots as a witness tree but did not occur as a present day tree.

In the hydric site unit, longleaf pine occurred 50 pecent as a witness tree and did not occur as a present day tree. Tupelo occurred 17 percent as a witness tree and 100 percent as a present day tree. P. oak (post oak (*Quercus stellata*)) and water oak (*Quercus nigra*) occurred 17 percent as witness trees but did not occur as present day trees in the hydric site unit.

DISCUSSION

Methodology used in plot location of this study differed from traditional LEC. To achieve accurate representation of the relationship between environmental variables and vegetation, LEC plots are located in areas with "steady-state" vegetation. Field plots in this study were positioned around the relative locations of known witness trees regardless of the state of the present day forest. For this reason, plots were distributed through a wide range of vegetation and sites that varied from dry, xeric uplands to standing water wetland areas. Since the determination of plots was based on the location of witness trees, some communities were excluded from the plots. For this reason, the classification may not necessarily represent a continuum in vegetative communities across all environmental gradients. It should be noted that none of the witness trees were located on the ground.

Four distinct vegetative communities were delineated occurring across a soil moisture gradient. These site units were found to reoccur on the landscape. Soil texture and terrain shape had significant influences on the moisture regimes across the landscape. Percent clay and depths to the clay were all discriminating variables in the site units delineated by discriminant analysis. This study demonstrated environmental variables that can be related to vegetation in areas of high disturbance such as the southeastern United States although they may not be the only factors at work shaping vegetation.

The incorporation of historical records into a GIS can greatly aid in spatially viewing past vegetation and land use. This was integral in mapping historic witness trees and the comparison of past and present day vegetation. The decrease in longleaf pine since the time of the historic records was the most apparent pattern.

REFERENCES

Braun-Blanquet, J. (1932/1951) Plant Sociology: the Study of Plant Communities. (English Translation), New York: McGraw-Hill.

Brenner, R.N. and J.K Jordan. 1991. The Role of an Ecological Classification System. In: The Symposium on Systems Analysis in Forest Resources; 1991 March 3-7; Charleston, SC: 70-80.

Carter, R. 1994. Landscape Ecosystem Classification of Successional Forest Types on the Highlands Ranger District, Nantahala National Forest in North Carolina. Clemson, S.C: Clemson University, Clemson, S.C. M.S. thesis.

Foth, H.D.; H.S. Jacobs; L.V. Withee. 1971. Laboratory manual for introductory soil science. 3rd ed. Dubuque, IW: W.C. Brown Co. Publishers. 104 p.

Hill, M.O. 1979a. DECORANA: A FORTRAN program for detrended correspondence analysis and reciprocal averaging. Dept. of Ecology and Systematics. Ithaca, NY: Cornell University. 52 p.

Hill, M.O. 1979b. TWINSPAN: A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ithaca, NY: Dept. of Ecology and systematics, Cornell University. 90 p.

Hill, M.O. and H.G. Gauch. 1980. Detrended Correspondence Analysis, an improved ordination technique. Vegetatio 42: 47-58.

Jones, S. M. 1989. Application of landscape ecosystem classification within the Southeastern United States. In: Proceedings of the Forest Ecology Session, Soc. Of Am. Foresters National Convention;1989 September 24-27; Spokane, WA: 79-83.

Long, B.M. 1980. Soil survey of Berkley County, South Carolina. National Cooperative Soil Survey: USDA, SCS, S.C. Land Res. Cons. Comm. and S.C. Ag. Exp. Station.

Marks, P.L; P.A. Harcombe. 1981. Forest vegetation of the Big Thicket, Southeast Texas. Ecological Monographs. 51: 287-305.

McCune, B.; M.J. Mefford. 1995. Multivariate Analysis of Ecological Data, Version 2.0. MjM Software Design, Gleneden Beach, Oregon, USA.

McNab, W. H. 1989. Terrain Shape Index: Quantifying effects of minor landforms on tree height. Forest Science 35(1): 91-103.

McNab, W. H. 1993. A topographic index to quantify the effect of mesoscale landform on site productivity. Canadian Journal of Forest Research. 23: 1100-1107.

Petitgout, P.; S.M. Jones. 1995. Landscape Ecosystem Classification of the Lower Terraces within the Coastal Flatwoods Region of South Carolina. Masters Thesis. Department of Forest Resources, Clemson University, Clemson, SC.

SAS Institute. 1990. SAS Users's Guide: Statistics. Version 6 ed. SAS Institute, Cary, North Carolina. 584 p.

Schafale M. P.; P.A. Harcombe. 1983. Presettlement vegetation of Hardin County, Texas. The American Midland Naturalist, 109: 153-172.

Stich, R. F. 1994. Integration of soils and landform in the refinement of a Landscape Ecosystem Model: Hilly coastal plain province, South Carolina. Clemson, SC: Clemson University, Department of Forest Resources. Masters Thesis.

APPLICATION OF PIEDMONT LANDSCAPE ECOSYSTEM CLASSIFICATION AS A REFERENCE FOR A VEGETATION AND HERPETOFAUNAL SURVEY ON LAKE THURMOND, SC

Victor B. Shelburne, Lawrence R. Gering, J. Drew Lanham, Gregory P. Smith, Thomas M. Floyd, and Eran S. Kilpatrick[1]

Abstract—Application of a Piedmont landscape ecosystem classification methodology was used as a basis for a survey of vegetation and herpetofaunal communities on a 343 hectare (846 acre) tract on Lake Thurmond near Plum Branch, SC. The site is located in the Carolina Slate Belt of the Midlands Plateau Region of the Piedmont province. A total of 160 plots were established and 30 were sampled intensively for vegetation. Herpetofaunal populations were sampled within 6 sites, representative of habitat types found throughout the site, using drift fences and pitfall traps.

Nearly 180 species of plants were documented and classification and ordination revealed the expected array of plant communities in an area that has not as yet achieved a steady state plant community. Landscape Ecosystem Classification revealed five site units in a repeating pattern across the site. Herpetofaunal communities were documented across the area by habitat type. Thirty species of herpetofauna were captured or otherwise recorded. This total included species from 2 classes (Amphibia, Reptilia), 4 orders (Caudata, Anura, Testudines, Squamata), and 2 suborders (Lacertilia, Serpentes). Species richness and abundance were greatest at depression wetlands (18), followed by riparian zones (16) and uplands (11). Depression wetlands and riparian zones should be given the highest priority in conserving critical habitats for herpetofauna on the training site.

Through the use of geographic information systems (GIS), a map showing the location of the various site types in relation to the vegetation and herpetofaunal communities was produced. These data may provide valuable reference information for the landowner.

INTRODUCTION

The South Carolina Army National Guard (SCARNG) and the Department of Forest Resources at Clemson University developed a cooperative research project to survey the vegetation and herpetofaunal resources at the SCARNG's Clarks Hill Training Site. The project included four phases or components: 1.) a vegetative communities survey, 2.) a flora survey, 3.)a herpetofaunal survey, and 4. the development of a geographical information system (GIS) for storing and displaying data associated with the three surveys.

The application of a Piedmont Landscape Ecosystem Classification methodology was used as a basis for determining forest communities and as a framework to survey the area's flora (Jones 1991). The methodology uses percent clay in the B horizon, depth to maximum clay, landform index, terrain shape index, and aspect as discriminators in classifying sites along a continuum from xeric to mesic.

The Piedmont is one of the most anthropogenically disturbed physiographic regions in the southeastern United States. According to Godfrey (1997), forests regenerating on abandoned agricultural lands dominate the central Piedmont. As such, the area "...offers splendid laboratories in which to watch the advance of plant succession." (Godfrey 1997). Over 130 species of reptiles and amphibians have been recorded in South Carolina (Martof and other 1980, Zingmark 1978). Standardized methods were used to survey reptiles and amphibians inhabiting the training site and to assess the herpetofauna community composition and distribution in representative habitats across the site (Heyer and others 1994). For species of particular interest (high abundance, conservation concern, extralimital occurrence) notes on natural history and management implications are also included.

The results of the vegetative communities survey, flora survey, and herpetofaunal survey were incorporated into a GIS for data storage and display. These results were compiled into a series of themes or layers suitable for use by by ArcView® and/or ArcInfo®.

[1]Associate Professor, Assistant Professor, Assistant Professor, Graduate Residence Assistants, Department of Forest Resources, Clemson University, Clemson, SC., respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

OBJECTIVES

1. Describe the distribution and extent of plant alliances on the Clarks Hill Training Site.
2. Map the areal extent of ecological landtype phases using the Piedmont Landscape Ecosystem Classification (LEC) model.
3. Survey the site for vascular plants using verified nomen clature, classification and annotation.
4. Denote plots and flora listing with an associated map showing plot locations as determined by GPS.
5. Record species of reptiles and amphibians in represen tative habitats.
6. Render management recommendations regarding the conservation of herpetofauna communities.

METHODS

Study Site

The 343 hectare (846 acre) Clarks Hill Training Site tract is a peninsular landform bounded by Lake Thurmond (Clarks Hill Lake). The training site is located within the Carolina Slate Belt in the South Carolina Piedmont physiographic province (Myers and others 1986). Terrain in this region is typified by narrow floodplain bottomlands, streams and gently rolling uplands. Elevation ranges from 37 m to 214 m above mean sea level.

Most of the soils are Typic Hapludults with occasional Aquic Hapludults and Typic Dystrochrepts (Gay 1992, Smith and Haybeck 1979). Surface horizons are usually brown and loamy with an underlying argillic clay horizon. The growing season is approximately 215 days from late March to early November and the average rainfall of 120 cm is evenly distributed throughout the year (Gay 1992).The dominant forest cover type is a relatively homogeneous natural stand of 50-60 year old loblolly pine (*Pinus taeda*). Visual inspection of the site indicated historical disturbances (probably agricultural). Lotic water features within the training site include several "dry" branches (intermittent creeks) that flow into some of the lake's many coves. The only known lentic features within the site were 4 depression wetlands. These wetlands had a higher proportion of hardwood species than surrounding upland sites.

Methodology and Data Analyses: Ecosystem Classification
A 20m x 20m plot was established in the fall of 1999 at each point using the methodology as described in the North Carolina Vegetation Survey (NCVS) (Peet and others 1998). Plots were usually located in the geometric center of the stand but were occasionally adjusted to insure homogeneous species composition and uniform stand structure within the plot. The tree stratum (dbh > 11.4 cm) was sampled by species and diameter within the 0.10 ha plot, and the sapling and shrub stratum (>1.4 m tall, less than 11.4 cm dbh) was sampled by species and diameter class as indicated by the survey methodology. Tree seedlings, low shrubs, herbaceous species, and rhizomatous shrubs were tallied by species and in frequency classes in the whole plot.

Landform and soil variables were also examined at each plot. Landform index was derived from the mean of eight measurements in percent scale taken with a clinometer at forty-five degree spacings from plot center to the surrounding horizons. Terrain shape index (TSI) was determined at each plot to determine microsite convexity or concavity. Soil samples were systematically collected from three locations within the plot using an auger. Using averages from the three collection sites, depth of A and E horizons, epipedon thickness, and soil solum depth were determined. Vegetation data are summarized by species for each intensive plot. Cover classes for all species (trees, shrubs, herbs, vines, and seedlings) are noted for each plot. Plots are then referenced on maps within a GIS (phase 4 of this project).

Presence is defined as the occurrence of a species (based on emergence of a stem or stems) within an area of a given size and location. Presence is a vegetation parameter compatible across all plant growth forms that can be used for many analytical procedures (ordination and classification). Presence/absence data taken from the nested plots in the NCVS provide fundamental data for characterization of community composition and structure (Peet and others 1998).

Cover is defined as the percentage of ground surface obscured by the vertical projection of all aboveground parts of a given species onto that surface. Percentage cover provides an index of a species' potential contribution to community production. In the NCVS protocol, cover is the only quantitative vegetative parameter compatible across all plant growth forms. Percent cover was estimated visually by the researcher during this study. The cover classes and percentage cover ranges that used in this study were: 1 = trace, 2 = 0-1 percent, 3 = 1-2 percent, 4 = 2-5 percent, 5 = 5-10 percent, 6 = 10-25 percent, 7 = 25-50 percent, 8 = 50-75 percent, 9 = 75-95 percent, 10 > 95 percent (Peet and others 1998).

A series of multivariate techniques was used for analysis of data. Detrended Correspondence Analysis (DCA) (DECORANA, Hill 1979a), which ordinates species and samples simultaneously, was the method of ordination used to analyze vegetation data (McCune and Mefford 1999). DCA or DECORANA© was used to analyze species abundance by organizing and displaying data in multidimensional space (Hill 1979a).

Cluster analysis of vegetation was performed by Two Way Indicator Species Analysis (TWINSPAN, Hill 1979b). TWINSPAN© is a polythetic diverse classification that simultaneously classifies both species and plots using the main matrix for vegetation data (McCune and Mefford 1999). This is a subjective classification, and allows the investigator to draw a separation between the groups in the initial ordination of plots (Hutto and others 1999). TWINSPAN was used in conjunction with DCA to reduce this subjectivity while delineating groups of similar plots. TWINSPAN was also used to identify indicator or diagnostic species that were strongly correlated to a certain community association.

A landscape ecological classification model developed by Jones (1988, 1991) was employed. This model uses depth

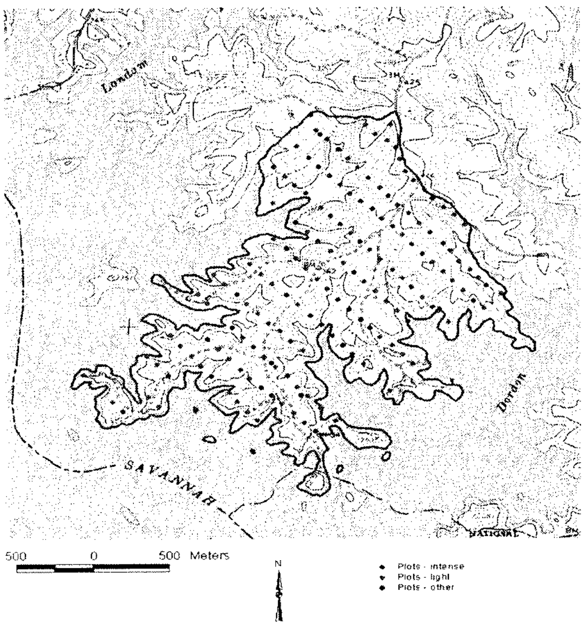


Figure 1—Location of 160 plots on the South Carolina Army National Guard training site on Lake Thurmond in South Carolina.

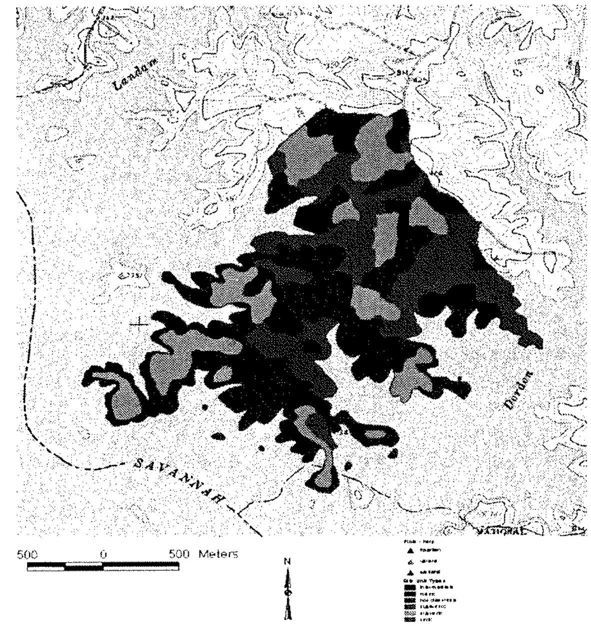


Figure 2—Five site units, determined by Landscape Ecosystem Classification, South Carolina Army National Guard training site on Lake Thurmond in South Carolina.

to maximum clay, percent clay, aspect, landform index and terrain shape index. The actual basis for using this model is based on the conclusion by Gay (1992) that the Jones model for the Interior Uplands Plateau in the Piedmont was compatible with the Slate Belt Subregion in the Piedmont. Transects were established throughout the site at an approximate sampling ratio of one survey plot for every five acres. Transect lines were spaced 201.2 meters (10 chains) apart and plot centers were located at intervals of 100.6 meters (5 chains) along the transect lines. Global positioning system (GPS) technology was used to record the location of the plot centers. On each of the 160 plots, data on Landform Index, aspect, soils and presence/frequency of overstory species were collected. Every fifth plot of this systematic sample was designed to be an "intensive plot" where additional data on the understory flora were collected. This process resulted in 30 intensively surveyed plots and 130 lightly surveyed plots (figure 1). All data were compiled by cover type and landtype phase (mesic, sub-mesic, intermediate, sub-xeric and xeric) by plot in both tabular and map formats.

Herpetofaunal Sampling

Six study sites, representative of the habitat types of the surrounding landscape, were established for herpetofaunal sampling. These sites included 2 depression wetland sites, 2 riparian sites along creeks, and 2 upland sites. Trapping methods included drift fences with pitfalls and cover-boards. Drift fences were 10m long x 0.6m high silt cloth with 2 pitfall traps (each a 5 gallon bucket, buried flush with the soil surface) at each end of the fence for a total of 4 pitfalls/fence. A total of 24 fences (4/site) and 96 pitfalls (16/site) were installed among depression wetland, riparian, and upland sites. A total of 24 coverboards (0.6m x 1.2m, plywood and tin) were installed within two of the study sites (12 within a riparian site and 12 within a depression wetland site). During monitoring sessions, aural surveys were conducted to record the presence of frog (Anuran) species. Area/time constrained searches to record species or individuals that may not have been captured in traps, were also conducted. Individuals that were captured were identified to species and sex (when possible), and released on the opposite side of the drift fence from which they were captured.

RESULTS AND DISCUSSION

Ordination and Cluster Analysis

Ordination arranged the intensive plots along two axes that together represented a possible soil moisture gradient. Based on ordination and cluster analysis (classification), the plots were separated into three groups. An evaluation of the classification analysis for all plots indicated that there were many plant species which were not preferential; in other words, many species were not found in greater abundance in one group over another. This pattern fits the expectation for the earlier stages of succession which these plots mostly represent.

Community and Floral Survey

Most of the tract is dominated by 50 - 60 year old loblolly and shortleaf pine. Five site units were mapped on the site (figure 2): Xeric (3.6 hectares; 1 percent of the area); Sub-xeric (77 hectares; 23 percent); Intermediate (156 hectares; 46 percent); Sub-mesic (89 hectares; 26 percent); Mesic (15 hectares; 4.5 percent); 180 plant species were described on the 30 intensive plots.

A description of these site units is as follows. 1.) Xeric sites are the driest, most exposed sites. They are the most unproductive sites since either a combination of high clay content close to the soil surface or the location of the site (i.e., exposed ridges which do not retain moisture) makes for poor growing conditions for most species. Loblolly pine site index (index age 50) is generally 60 feet on these xeric sites. 2.) Sub-xeric sites exhibit slightly higher productivity either through a combination of lower clay content, greater depth to maximum clay or less exposure. This is a fairly common site type throughout the South Carolina Piedmont. Site index for loblolly pine in these sub-xeric sites is approximately 70 feet. 3.) The intermediate site unit is also fairly common and makes up the plurality of sites on this tract. Clay is usually not as close to the soil surface or there is some combination of aspect and exposure which provides a greater degree of site protection creating higher moisture retention in the soil. Site index for loblolly pine in these intermediate sites is approximately 80 feet. 4.) Sub-mesic site units usually exhibit a much reduced clay content that is at least 12 inches or more from the soil surface. Likewise, landform indices are generally high, reducing exposure to the drying effects of the sun. These sites generally occur on lower and north facing slopes where there is greater moisture retention due to runoff from upper slopes and more protection. Site index for loblolly pine in these sub-mesic sites is approximately 90 feet. 5.) Finally, mesic sites exhibit a combination of low clay content, high landform indices and north facing slopes. However, not all three factors must be present for a mesic site to occur. These sites also occur along stream bottoms and cove sites. They exhibit the greatest degree of moisture retention because of their place on the landscape. Site index for loblolly pine in these mesic sites can exceed 100 feet.

The determination of site unit scores and the actual location of site units is subject to some error. At best, there is a 20 percent chance that any particular point will be either a site unit higher or lower than is actually determined. This is due to microsite variations not picked up in the sampling scheme. Also, there is some inherent error in the model itself. Therefore, these data and mapping units are most suitable for planning purposes in terms of overall site productivity of an area.

Herpetofaunal Survey

Thirty species of herpetofauna were captured or otherwise recorded as occurring on the training site from May 12, 2000 through January 27, 2001. This total included species from 2 classes (Amphibia, Reptilia), 4 orders (Caudata, Anura, Testudines, Squamata) and 2 suborders (Lacertilia, Serpentes). Species richness and abundance were greatest at depression wetlands (18), followed by riparian zones (16) and uplands (11). Ambystomatide salamanders (mole salamanders) were the most frequently captured taxa among all sites with most captures occurring in depression wetlands.

The overall herpetofauna richness (represented as the number of species), showed a relatively uniform distribution by taxa. The taxon with the fewest species was Testudines (four turtle species), and the taxon with the greatest number of species was Serpentes (nine snake species). The overall herpetofauna abundance (represented by the number of individuals captured or observed) shows an unequal distribution by taxa. There were relatively few individuals in the order Testudines and suborder Serpentes and a moderate number in the order Anura (frogs) and suborder Lacertilia (lizards). The order Caudata had the greatest number (476) of individuals captured or observed.

The depression wetlands habitat type had the greatest number of individual amphibian captures (542) while the riparian and uplands habitat types had fewer individual amphibian captures (33 and 16, respectively). However, the number of individual reptiles was fairly uniform across all three habitat types. Separating the two classes into orders and suborders shows that the greatest number of individuals captured was salamanders in wetland depression sites (456 individual captures). Though of lesser numbers, the dominant taxa in the riparian habitats were salamanders and frogs. Lizards were the dominant taxa in the upland habitat (22 individual captures).

CONCLUSIONS AND RECOMMENDATIONS

The Piedmont Landscape Ecosystem Classification methodology provided a working framework for classifying sites on the tract. Although classification of the sites provided a framework for a floral survey, ordination and classification of the vegetation did not distinguish between the five site units due to the mid-successional status of the landscape. Depression wetlands and riparian zones should be given the highest priority in conserving critical habitats for herpetofauna. This should include reserving appropriate buffers around depressions and along streams.

Species most sensitive to disturbance are likely to be Ambystomatid salamanders (mole salamanders). These species rely on ephemeral wetlands for breeding habitats. The occurrence of *Ambystoma talpoideum* (mole salamander) at the training site is noteworthy since it is believed to occur mostly as a Coastal Plain species in South Carolina. Surrounding uplands are important as buffers but also as non-breeding habitats for many species. The four-toed salamander (*Hemidactylium scutatum*), a disjunctly distributed species, occurs on the training site in riparian areas and areas adjacent to wetland depressions. By nature of its limited distribution in South Carolina, its status and conservation should also be a priority.

REFERENCES

Gay, J. U. 1992. Landscape ecosystem modelling of forested ecosystems within the Carolina Slate Belt region of South Carolina. Department of Forest Resources, Clemson, SC: Clemson University. Masters Thesis. 107 p.

Godfrey, Michael A. 1997. Field Guide to the Piedmont. University of North Carolina Press. 524 p.

Heyer, W.R.; M.A. Donnelly; R.W. McDiarmid; L.C. Hayek; M.S. Foster, eds. 1994. Standard Techniques for Inventory and Monitoring. In: Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Washington, D.C: Smithsonian Institution Press: 75-141.

Hill, M.O. 1979a. DECORANA: A FORTRAN program for detrended correspondence analysis and reciprocal averaging. Dept. of Ecology and Systematics. Ithaca, New York: Cornell University. 52 p.

Hill, M.O. 1979b. TWINSPAN: A FORTRAN program for averaging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ithaca, NY: Department of Ecology and Systematics, Cornell University. 52 p.

Hutto. C. J.; V. B. Shelburne; S. M. Jones. 1999. Preliminary ecological land classification of the Chauga Ridges Region of South Carolina. Forest Ecology And Management. 114: 383-393.

Jones, S.M. 1988. Old-growth forests within the Piedmont of South Carolina. Natural Areas Journal 8(1): 31-37.

Jones, S.M. 1991. Landscape Ecosystem Classification for South Carolina. In: Proceedings of a Symposium: Ecological land classification: applications to identify the productive potential of southern forests. Gen.Tech. Rep. SE-68. Ashville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 59-68.

Martof, B.S. , W. M. Palmer, J. R. Bailey, J.R. Harrison, III. 1980. Amphiabians and Reptiles of the Carolinas and Virginia. Chapel Hill, NC: The University of North Carolina Press. 264 p.

McCune, B.; M. J. Mefford. 1999. PC-ORD. Multivariate Analysis of Ecological Data, Version 4. MJM Software Design, Gleneden Beach, Oregon, USA.

Myers R. K.; R. Zahner; S.M. Jones. 1986. Forest Habitat Regions of South Carolina. Clemson University, Dept. of For. Research Series No. 42. 31 p.+map

Peet, R.K.; T.R. Wentworth; P.S. White. 1998. A Flexible, multipurpose Method for Recording Vegetation Composition and Structure. Castanea. 63: 262-274.

Smith, B.R.; D.C. Haybeck. 1979. General Soil Map, South Carolina. S.C. Agricultural Experiment Station, Clemson, SC: Clemson University.

Zingmark, R.G. 1978. An annotated checklist of the biota of the coastal zone of South Carolina. Columbia,SC: University of South Carolina Press. 364 p.

COARSE WOODY DEBRIS OF A PRERESTORATION SHORTLEAF PINE-BLUESTEM FOREST

Martin A. Spetich, Hal O. Liechty, John A. Stanturf, Daniel A. Marion, Kenneth Luckow, Calvin E. Meier, and James M. Guldin[1]

Abstract—The shortleaf pine-bluestem ecosystem was once a significant component of the Ouachita Mountains. However, fire suppression over the past century has reduced this complex. To address this loss, the Ouachita National Forest plans to restore approximately 155,000 acres of shortleaf pine-bluestem through understory, overstory, and fire treatments. We do not fully understand effects of these treatments on biotic and abiotic components of the forest. Our study of one component, coarse woody debris, is a portion of a larger study to examine ecosystem changes. Our treatments will include overstory thinning to 65 feet^2 per acre (approximately half that of the control), removed of the midstory and understory, and moderate intensity fires at 2- to 5-year intervals. Pretreatment values indicate total coarse woody debris volume (standing + down) did not differ between control and treatment (treatment area = 94 feet^3 per acre (SE ± 10.3); control = 110 feet^3 per acre (SE ± 46.9)), (p-value = 0.62, a = 0.05). However, due to initial differences in the woody debris components (e.g., species and decomposition class) between the pre-treatment area and control area, percent change within the pre-treatment area will be a better measure of change over time.

INTRODUCTION

Coarse Woody Debris

Coarse woody debris is important as habitat for forest organisms (Larson 1992, Maser and others 1979, Maser and others 1988, Maser and Trappe 1983, Meyer 1986, Muller and Yan Liu 1991, Thomas and others 1979, Van Lear 1993) and acts as reservoir for nutrients and carbon (Bray and Gorham 1964, Edmonds 1987, Harmon and others 1986, Lang and Forman 1978, Maser and others 1988).

Many organisms are associated with standing and down wood. Forty-five bird species use standing dead trees and 20 species use down woody debris in southern US forests (Lanham and Guynn 1996). In the southeastern US, at least 23 mammal species use standing dead trees and at least 55 mammal species use down wood (Loeb 1996). Ausmus (1977) found greater organic matter, nematode density, and root biomass in soil beneath log litter than under leaf litter. Reptiles and amphibians have been associated with coarse woody debris and their diversity may be linked with the quality and amount of coarse woody debris (Whiles and Grubaugh 1996). Earthworms may use deadwood for cover and microbial biomass as food (Hendrix 1996). Finally, Barnum and others (1992) found that mice select down logs as the most widely used substrate for travel in Minnesota and Maryland.

Ecosystem Management Research Project

The Ouachita Mountains Ecosystem Management Research Project (OEMP) is a large-scale interdisciplinary effort designed to provide the scientific foundations for watershed scale landscape management. The OEMP has progressed through three phases: developing natural regeneration alternatives to clearcutting and planting, testing these alternatives at the stand scale, and measuring cumulative impacts of landscape scale ecosystem management in the Upper Lake Winona Watershed. We divided this 16,274-acre watershed into six sub-watersheds, each with different management objectives and treatments. One of these, and the focus of this paper, is the 3,370-acre North Alum Creek sub-watershed, which is being managed to recreate a shortleaf pine-bluestem ecosystem.

The management goal is to restore a vegetation complex that existed prior to European settlement of the region. This vegetation complex was dominated by pines, primarily shortleaf (*Pinus echinata Mill*), with a minor hardwood component (mostly *Quercus* spp.) in the overstory. Frequent fires maintained a herbaceous understory dominated by bluestem grasses (*Andropogon gerardii Viaman* and *Schizachyrium scoparium* (Mich.) Nash), and restoration is designed to mimic these conditions. Treatments applied to the North Alum Creek sub-watershed will include overstory commercial thinning, midstory and understory removal, and cyclic burning.

[1]Research Forester, USDA Forest Service, Southern Research Station, Hot Springs AR 71902; Professor, School of Forest Resources, University of Arkansas at Monticello, Monticello, AR 71656; Soil Scientist, USDA Forest Service, Athens, GA 30602; Hydrologist, USDA Forest Service, Oxford, MS 38655; Soil Scientist, USDA Forest Service, Ouachita National Forest, Hot Springs, AR 71902; Research Forest Ecologist, USDA Forest Service, Southern Research Station, Hot Springs AR 71902, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

Over time, an area-based approach using even-aged reproduction methods, primarily two-aged shelterwoods, will achieve sustainability. Approximately 155,000 acres of shortleaf pine-bluestem ecosystems are planned to be restored on the Ouachita National Forest in Arkansas and Oklahoma.

In this study, we examine coarse woody debris (CWD) of the control area versus the proposed treatment area (defined as the pre-treatment area). Our long-term objective is to determine differences in volume and structure between the control and the restored site. The immediate objective of this study, summarized in this paper, is to compare baseline woody debris between an unharvested, unmanaged control area to the pre-treatment area.

METHODS

Future Treatment

Total basal area of the restoration treatment (65 $feet^2$ per acre) will be approximately half that of the control (118 $feet^2$ per acre). Hand lobor using chainsaws or handtools will remove the predominantly hardwood midstory and understory. We will conduct burning at 2- to 5-year intervals for 10 years, during the dormant or growing season, with moderate intensity fires. The resulting stands will be open and park-like.

Plot Layout and Measurements

We established 77 one-fifth-acre circular plots with a 52.7 ft radius, 65 plots located in the pre-treatment area and 12 in the control area. In each plot we measured both standing dead trees (snags) and down deadwood.

We measured all snags at least 4 inches d.b.h. on the fifth-acre circular plot. For each tree we recorded species, d.b.h., and height. We recorded five decay classes for hardwood trees and six classes for pines (table 1). These classes are:

(1) recently dead with tight bark, twigs and small branches present;

(2) dead, small branches broken, bark - loose and/or partly absent;

(3) dead, mostly large branches present, bark - trace to absent;

(4) dead with bark absent; broken top; heavily de cayed; soft, blocky structure (a 6-inch knife blade can be easily inserted 3 inches or more into the wood);

(5) soft and powdery or down (for snags this is a post-treatment measurement only);

(6) (Pine only): all but heartwood has decayed and fallen away.

For down wood ≥4 inches in diameter, in fifth-acre plots we measured length and midpoint diameter (figure 1). We recorded branches larger that 4 inches in diameter as separate pieces indicated by numbered segments (figure 1).

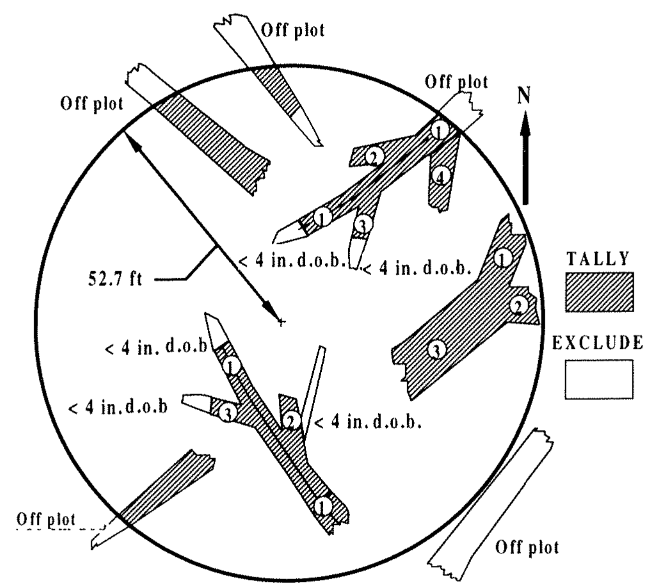


Figure 1—A typical fifth-acre circular plot. We measured all down deadwood ≥ 4 inches in diameter on the plot. Numbered segments were measured separately. Additionally, all standing dead trees (snags) ≥ 4 inches d.b.h. were measured on the plot (snags not pictured).

We calculated snag volume as:

$V = 1/3 \times H \times [B + B' + \mathrm{sqrt}(B \times B')]$

Where: V = volume in ft^3

H = height of tree main stem (ft)

B = cross sectional area of tree at dbh (ft^2)

B' = cross sectional area at the top of the stem (ft^2)

We calculated down deadwood volumes ($feet^3$) as length of segment multiplied by the midpoint cross sectional area. We compared mean volume of course woody debris between plots in the pre-restoration and control area plots using a one way ANOVA, alpha 0.05.

RESULTS

Total coarse woody debris volume (standing snag + down wood) was similar, with 110 $feet^3$ per acre in the control and 94 $feet^3$ per acre in the pre-treatment area. These values did not differ statistically (p-value = 0.62, a = 0.05) (figure 2). However, pine snag volume in the control plots was nearly double that of pre-treatment plots (figure 3). For down deadwood of pine, just the opposite was true, with a mean of 2.4 $feet^3$ per acre in the control plots versus 13.7 $feet^3$ per acre in pre-treatment plots.

Decomposition class 3 of the pine snag component in the control area had greater mean volume than any other class (figure 4). Class 4 dominated the pine down deadwood component in both the control and pre-treatment area (figure 5).

DISCUSSION AND CONCLUSIONS

Surprisingly decomposition class 5 was rarely recorded on our plots, although nearly all previous studies have shown this as a major component. However, class 5, often hidden

Table 1—Breakdown of decomposition classes for snags and down wood. Decomposition class 1 represents the least decomposed woody material and class 5 is the most decomposed woody material. Adapted from Cline and others (1980) and Maser and others (1979)

Deadwood type	Characteristic	Decomposition class 1	2	3	4	5
Snags	Branches and Crown	recently dead, twigs and small branches present	large branches present, mostly broken	large branch stubs present	absent	NA
	Bark	tight	loose and/or partly absent	trace to absent	absent	NA
	Bole	recently dead	standing, firm	standing, decayed	broken top, heavily decayed, soft, blocky structure	NA
Down wood	Bark	intact	intact	trace to absent	absent	absent
	Twigs > 1.2 in.	present	absent	absent	absent	absent
	Texture	intact	intact, sapwood partly soft	hard, solid interior, possible evidence of exterior decay	soft, blocky pieces	soft and powdery
	Shape	round	round	round	round to oval	oval
	Color of wood	original color	original color	original color to faded	original color to faded	heavily faded
	Portion of log on ground	log elevated on support points	log elevated on support points	log near or on ground	all of log on ground	all of log on ground

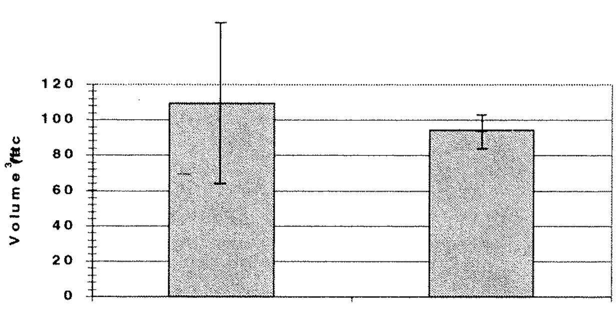


Figure 2—Total mean volume of standing plus down deadwood. Error bars represent standard error.

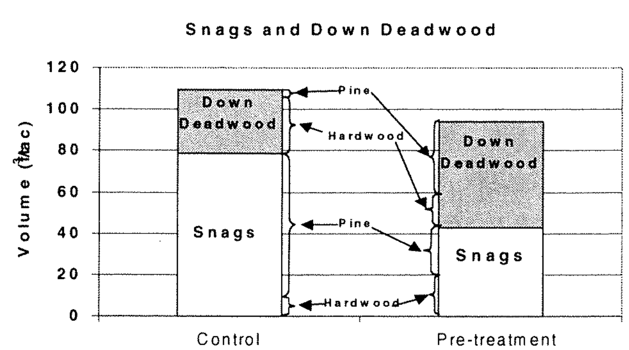


Figure 3—Snags and down deadwood volume (feet³ per acre) by pine or hardwood in control and future treatment area.

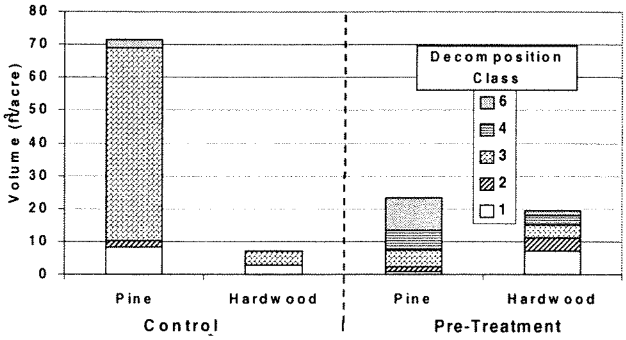


Figure 4—Mean volume of snags by species and decomposition class in control versus future treatment area. We used decomposition class 5 only for down deadwood.

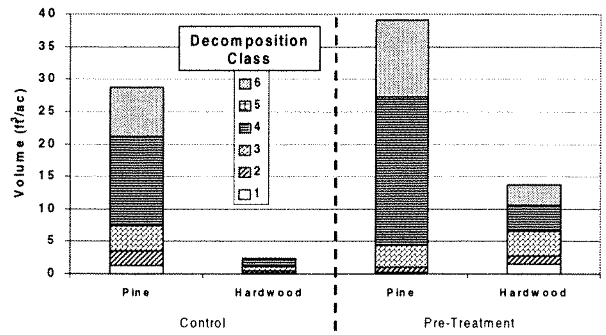


Figure 5—Mean volume of down deadwood by species and decomposition class in control versus future treatment area. Note that class 5, found only for pine on the pre-treatment area, was 0.1 feet^3 per acre.

under leaves, is the most difficult to detect. We plan to resample some plots to examine the possibility of undersampling. If not a sampling error, then this result would require closer examination of the dynamics and interacting organisms in the class 4 stage and beyond.

Other studies have found intermediate decay classes, such as our class 3, tending to be dominant (Harmon and others 1986, Shifley and others 1997, Spetich and others 1999, Spies and Cline 1988). However, only the pine snag component in the control area showed this relationship. Decomposition class 4 currently represents the largest volume when compared to the other decomposition classes.

For decomposition class 6 resin-impregnated pine is highly flammable, and the fire treatment will likely reduce its volume.

Post-treatment comparisons of deadwood volume in this study will require testing total deadwood volume changes between the control and treatment areas. Due to initial differences or high variability in the components (e.g. hardwood versus pine and decomposition class) between the treatment and control areas, percent and rate of change will be a better measure of comparison over time.

LITERATURE CITED

Ausmus, B.S. 1977. Regulation of wood decomposition rates by arthropod and annelid populations. In Lohm U.; Persson T., eds. Soil organisms as components of ecosystems. Proceedings of the 6th international soil zoology Colloquim; 1977 Stockholm, Sweden: Swedish Natural Science Research Council: Vol. 25. 180-192.

Barnum, S.A.; Manville, C.J.; Tester, J.R.; Carmen, W.J. 1992. Path selection by *Peromyscus leucopus* in the presence and absence of vegetative cover. Journal of Mammology. 73: 797-801

Bray, J.R.; Gorham, E. 1964. Litter production in forests of the world. Advances in Ecological Research, New York: Academic Press: 2: 101-157. Vol.2.

Edmonds, R.L. 1987. Decomposition rates and nutrient dynamics in small-diameter woody litter in four forest ecosystems in Washington, U.S.A. Canadian Journal of Forest Research. 17: 499-509.

Harmon, M.E., Franklin, J.F.; Swanson, F.J.; [and others]. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research. 15: 133-202.

Hendrix, P.F. 1996. Earthworms, Biodiversity, and Coarse Woody Debris in Forest Ecosystems of the Southeastern U.S.A. In: McMinn, J.W.; Crossley, D.A., Jr., tech. eds. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests: effect on biodiversity; 1993 October 18-20; Athens, GA. Ben. Tech. Rep. SE-94. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 43-48.

Lang, G.E.; Forman, R. T. 1978. Detrital dynamics in a mature oak forest: Hutcheson Memorial Forest, New Jersey. Ecology. 59(3): 580-595.

Lanham, J.D.; Guynn, D.C. Jr. 1996. Influence of Coarse Woody Debris on Birds in Southern Forests. In: McMinn, J.W.; Crossley, D.A., Jr., tech. eds. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests: effect on biodiversity; 1993 October 18-20; Athens, GA. Ben. Tech. Rep. SE-94. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 101-107.

Larson, F.R. 1992. Downed woody material in southeast Alaska forest stands. United States Department of Agriculture, Forest Service. Pacific northwest research station. Research paper PNW-RP-452. 1-12 p.

Loeb, S.C. 1996. The Role of Coarse Woody Debris in the Ecology of Southeastern Mammals. In: McMinn, J.W.; Crossley, D.A., Jr., tech. eds. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests: effect on biodiversity; 1993 October 18-20; Athens, GA. Ben. Tech. Rep. SE-94. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 108-118.

Maser, C.M.; Anderson, R.G.; Cormack, K. Jr.; [and others]. 1979. Dead and down woody material. In: Thomas J. W., ed. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agric. Handb. 533, Published in cooperation with the Wildlife Management Institute and U.S. Department of the Interior, Bureau of land management, Washington, D.C. U.S. Department of Agriculture Forest Service: 78-95.

Maser, C.M.; Cline, S.P.; Cormack, K. Jr.; Trappe, J. M.; Hansen, E.. 1988. What we know about large trees that fall to the forest floor. In: Maser, C.; Tarrant, R.F.; Trappe, J.M.; Franklin, J.F., eds. From the forest to the sea: a story of fallen trees. Gen. Tech. Rep. PNW-GTR-229. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 25-47.

Maser, C.M.; Trappe, J.M.. 1983. The fallen tree — a source of diversity. In: Proceedings of the 1983 convention of the Society of American Foresters, 1983 October 16-20; Portland, OR. SAF Publication 84-03, Washington, DC. 335-339.

Meyer, J. 1986. Management of old growth forests in Missouri. Habitat Management Series Number 3. Missouri Department of Conservation, Jefferson City, MO. 16 p.

Muller, R.N.; Yan Liu. 1991. Coarse woody debris in an old-growth forest on the Cumberland Plateau, Southeastern Kentucky. Canadian Journal of Forest Research. 21: 1567-1572.

Shifley, S.R.; Brookshire, B.L.; Larsen, D.R.; Herbeck, L.A.. 1997. Snags and down wood in Missouri old-growth and mature second-growth forest. Northern Journal of Applied Forestry. 14: 165-172.

Spetich, M.A.; Shifley, S.R.; Parker, G.R. 1999. Coarse woody debris in central hardwood old-growth forests. Forest Science. 45: 302-313.

Spies, T.A.; Cline; S.P. 1988. Coarse woody debris in forests and plantations of coastal Oregon. In: Maser, C.; Tarrant, R.F.; Trappe, J.M.; Franklin, J.F., eds. From the forest to the sea: a story of fallen trees. Gen. Tech. Rep. PNW-GTR-229. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 5-24.

Thomas, J.W.; Anderson, R.G.; Maser C.; Bull, E.L. 1979. Snags. In: Thomas, J.W., ed. Wildlife habitats in managed forests, the Blue Mountains of Oregon and Washington. Agric. Handb. 553. Published in cooperation with the Wildlife Management Institute and U.S. Department of the Interior, Bureau of land management, Washington, D.C. U.S. Department of Agriculture, Forest Service: 60-77.

Van Lear, D.H. 1993. Dynamics of coarse woody debris in southern forest ecosystems. In: McMinn, J.W.; Crossley, D.A., Jr., tech. eds. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests: effect on biodiversity; 1993 October 18-20; Athens, GA. Ben. Tech. Rep. SE-94. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 1-15.

Whiles, M.R.; Grubaugh, J. W. 1996. Importance of Coarse Woody Debris to Southern Forest Herpetofauna. Pages 94-100 in Biodiversity and Coarse Woody Debris In: McMinn, J.W.; Crossley, D.A., Jr., tech. eds. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests: effect on biodiversity; 1993 October 18-20; Athens, GA. Ben. Tech. Rep. SE-94. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 94-100.

Index of Authors

☆U.S. GOVERNMENT PRINTING OFFICE: 2002-765-022/00064

Index of Authors

Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

One hundred and twenty-four papers and three poster summaries address a range of issues affecting southern forests. Papers are grouped in 19 sessions that include pine nutrition, nurseries/seed and seedlings, ecophysiology, fire, pine thinning and spacing, wood quality/technology, hardwood thinning and spacing, hardwood nutrition, competition, pine natural regeneration, hardwood artificial regeneration, hardwood natural regeneration, biometrics, understory, site preparation, site preparation and classification, insects and disease/injury, long-term ecophysiology, and ecosystems.